US011167515B2

(12) United States Patent
Champa et al.

(10) Patent No.: US 11,167,515 B2
(45) Date of Patent: *Nov. 9, 2021

(54) **SYSTEM AND METHOD FOR FABRICATING AND CURING LARGE COMPOSITE STRUCTURES**

(71) Applicant: **SPIRIT AEROSYSTEMS, INC.**, Wichita, KS (US)

(72) Inventors: **Michael Arthur Champa**, Clearwater, KS (US); **John Patrick McPherson**, Haysville, KS (US); **Dennis Ray Malone**, Derby, KS (US)

(73) Assignee: **Spirit AeroSystems, Inc.**, Wichita, KS (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/783,226**

(22) Filed: **Feb. 6, 2020**

(65) **Prior Publication Data**

US 2021/0031475 A1 Feb. 4, 2021

Related U.S. Application Data

(63) Continuation-in-part of application No. 16/525,772, filed on Jul. 30, 2019.

(51) **Int. Cl.**

B29D 99/00	(2010.01)
B29C 33/00	(2006.01)
B29C 33/30	(2006.01)

(52) **U.S. Cl.**
CPC ***B29D 99/001*** (2013.01); ***B29C 33/305*** (2013.01)

(58) **Field of Classification Search**
CPC B29D 99/001; B29C 33/305; B29C 70/32; B29L 2031/3082
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,794,481	A *	6/1957	Anderson	B29C 33/02	156/163
3,165,569	A *	1/1965	Bright	B29C 43/00	264/313
5,071,506	A *	12/1991	Nelson	B29C 70/446	156/441
5,429,693	A *	7/1995	Rose	B29C 53/8016	156/161

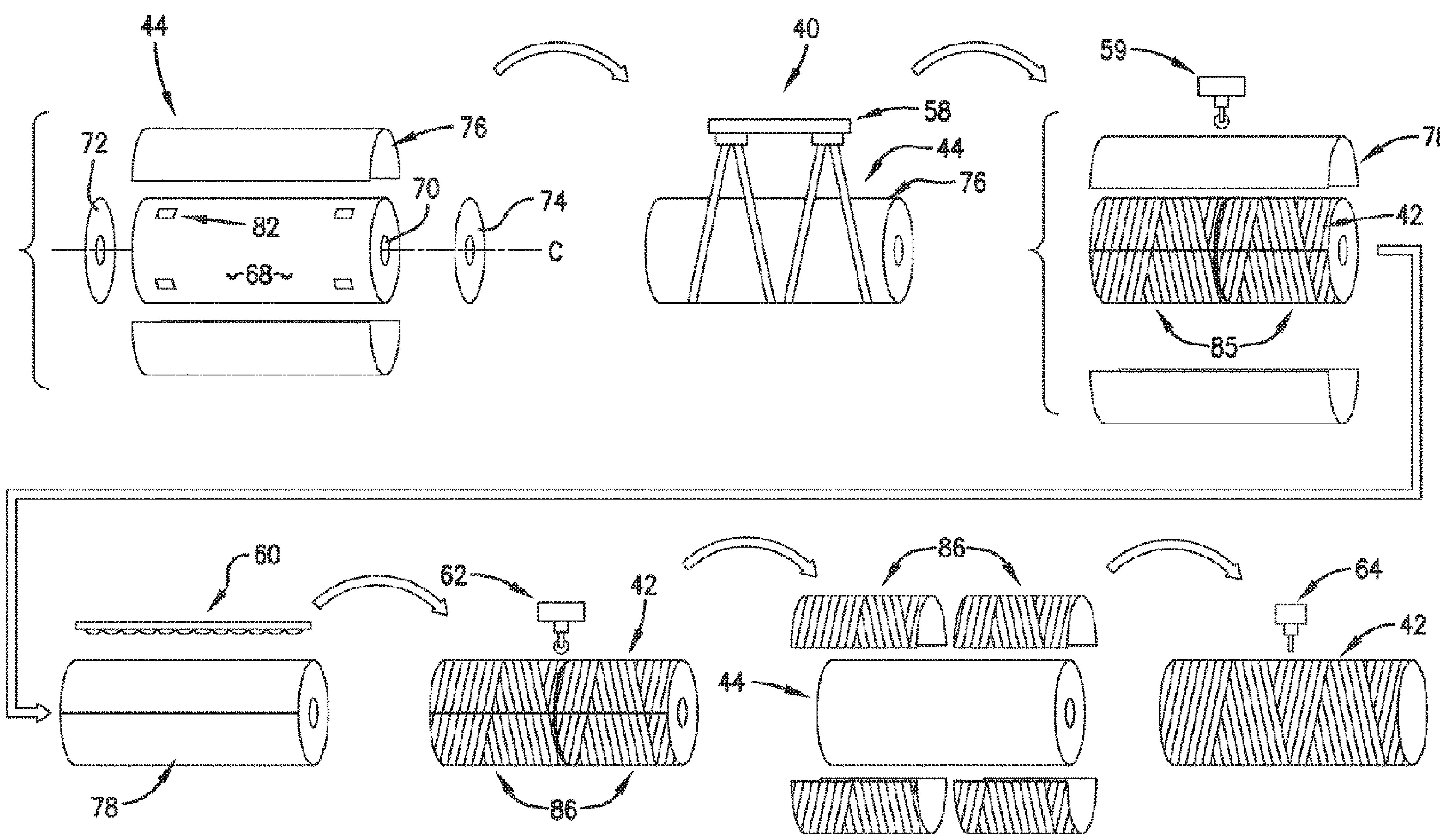
* cited by examiner

Primary Examiner — Jeffry H Aftergut
(74) *Attorney, Agent, or Firm* — Hovey Williams LLP

(57) **ABSTRACT**

A system and method for fabricating large composite fuselages or other vehicle structures, in which the composite structure is fabricated and cured as on a tool, segmented and removed from the tool without disassembling the tool, and then reassembled off the tool to reform the large structure. The tool includes mandrel segments attached to a substructure. The attachments may be moveable to accommodate differential expansion and contraction during curing, and the tool may be rotatable to facilitate access. A composite material of resin and synthetic fibers is applied over the mandrel segments to fabricate the structure on the tool. Caul plates are secured over the composite material, and the composite material is cured on the tool. The resulting structure is cut into part segments which are then removed from the tool, and the part segments are joined to reassemble the large composite structure off the tool.

20 Claims, 22 Drawing Sheets



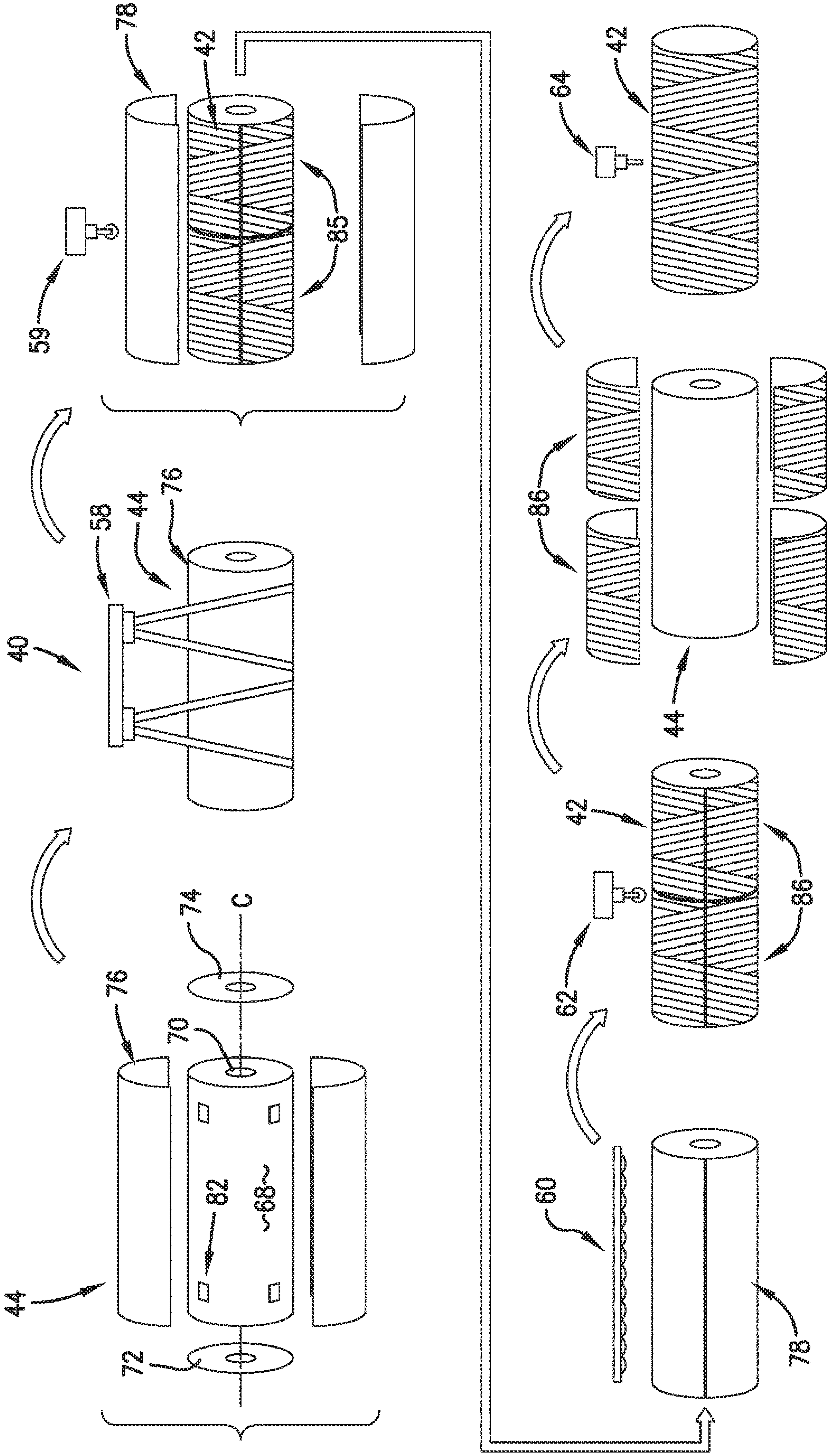


Fig. 1.

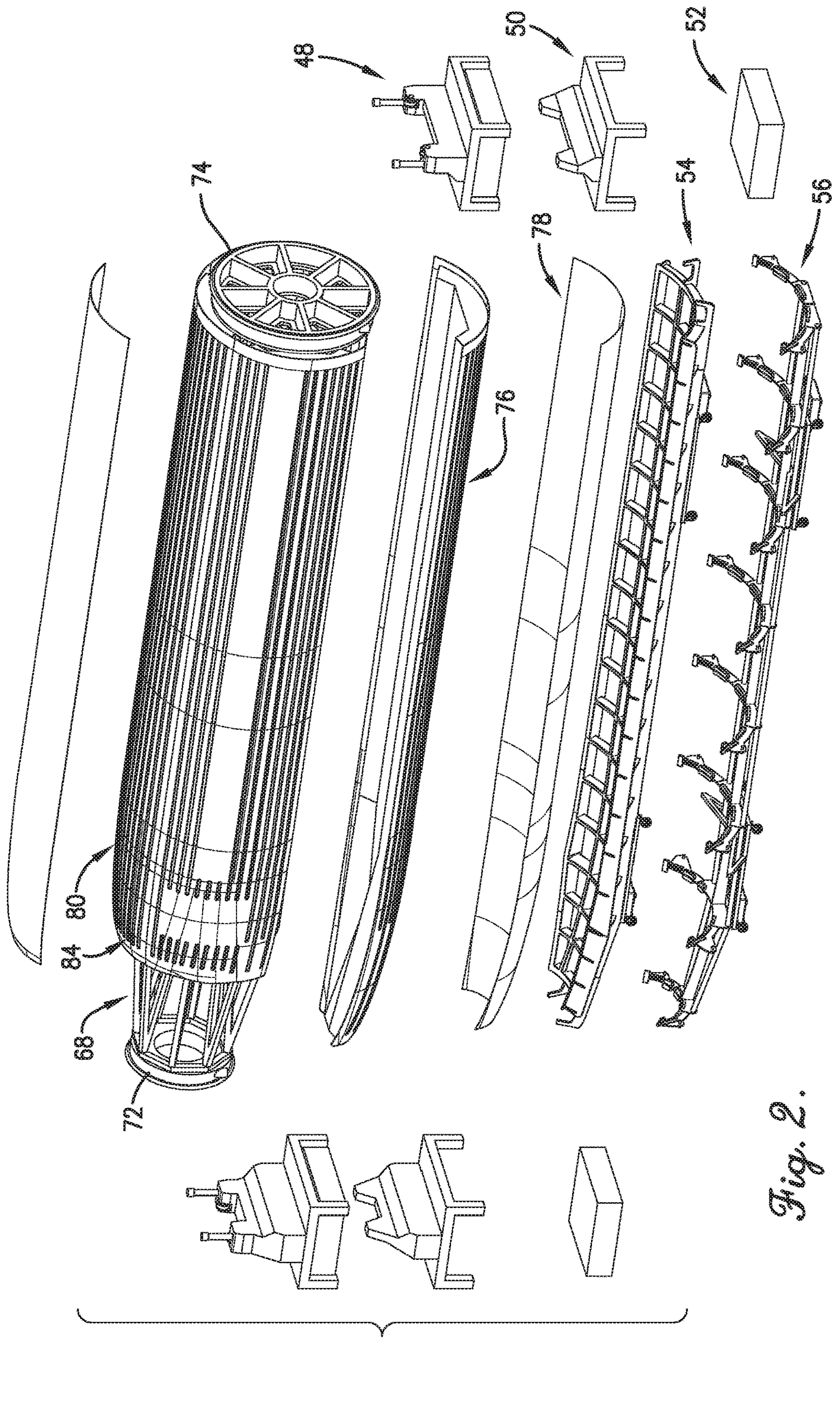


Fig. 2.

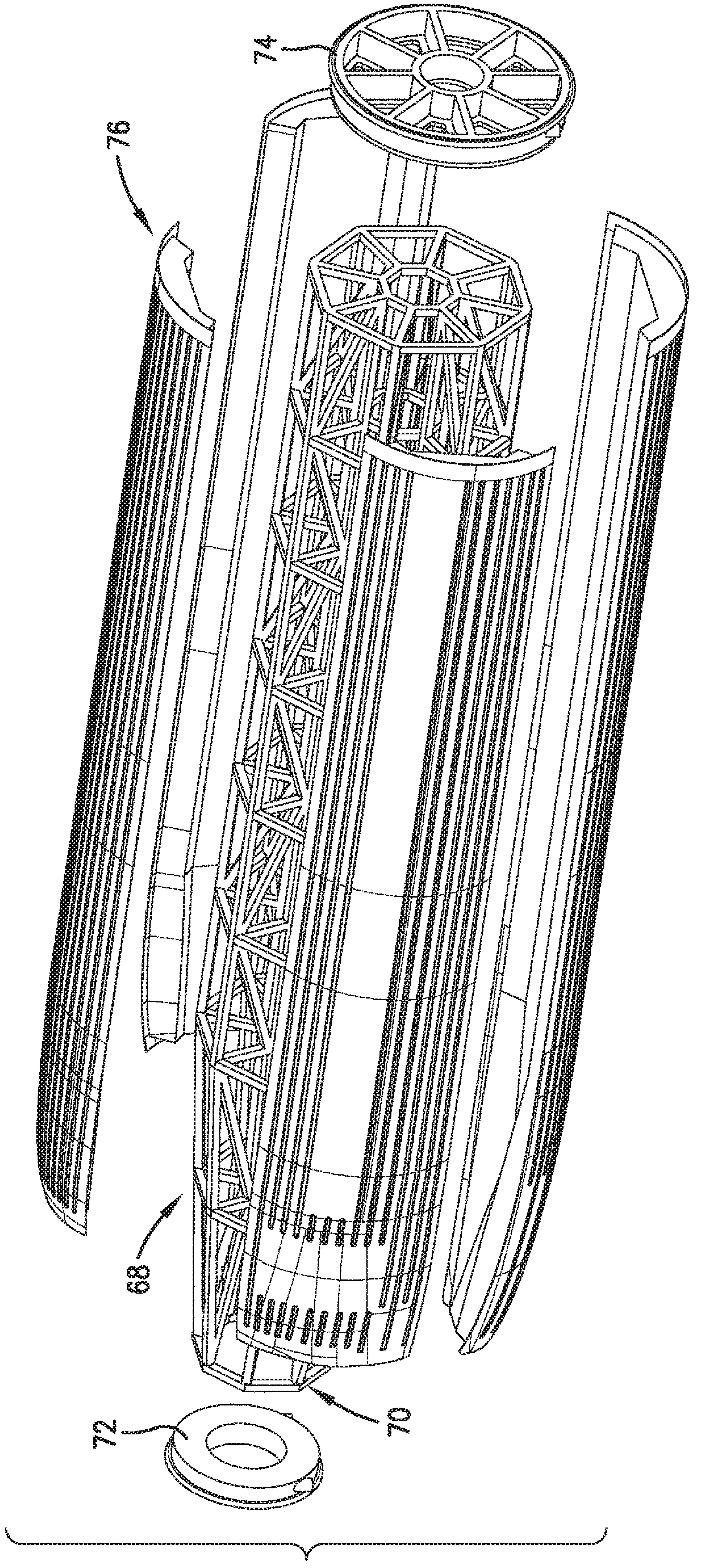


Fig. 3.

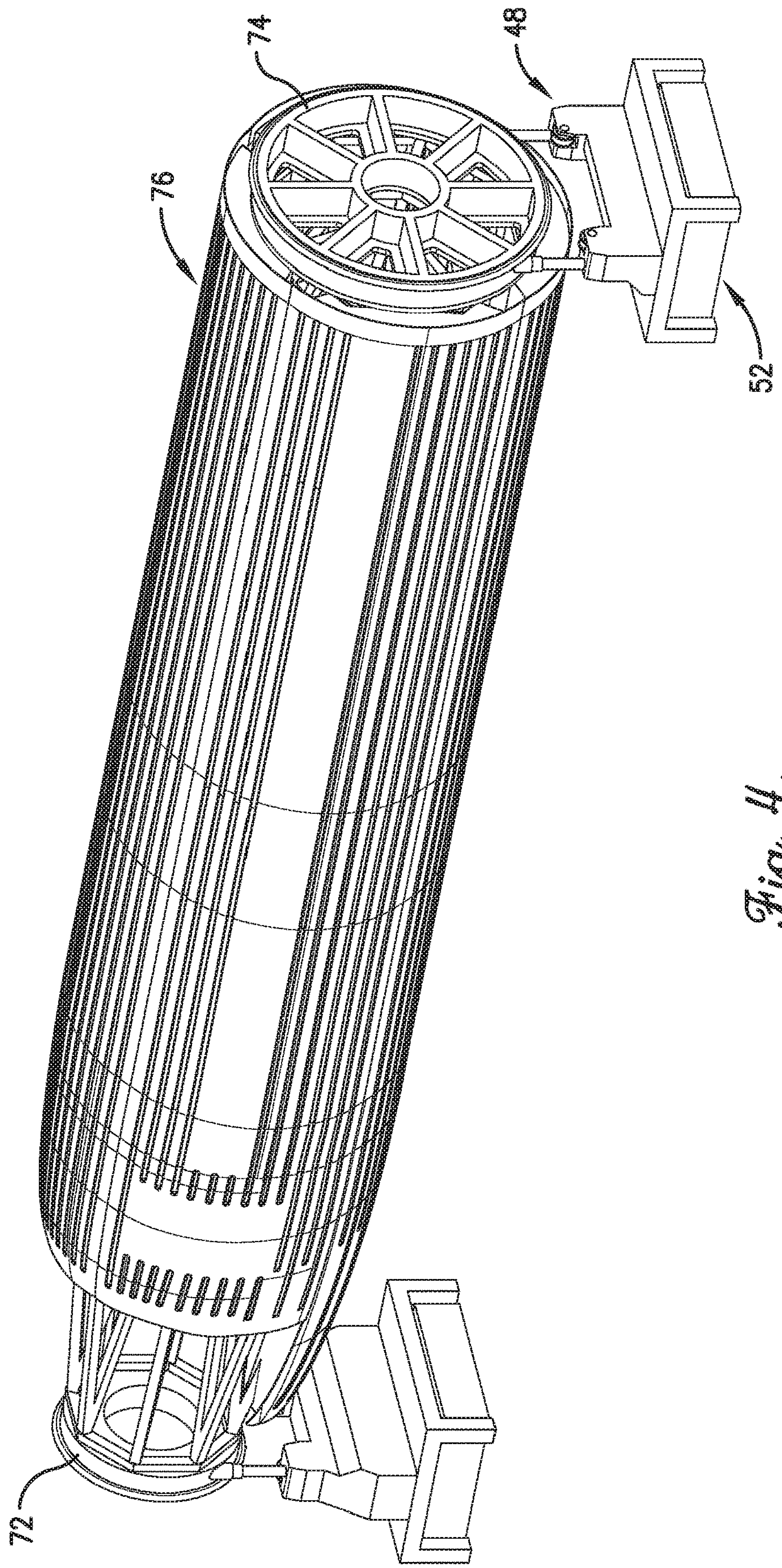


Fig. 4.

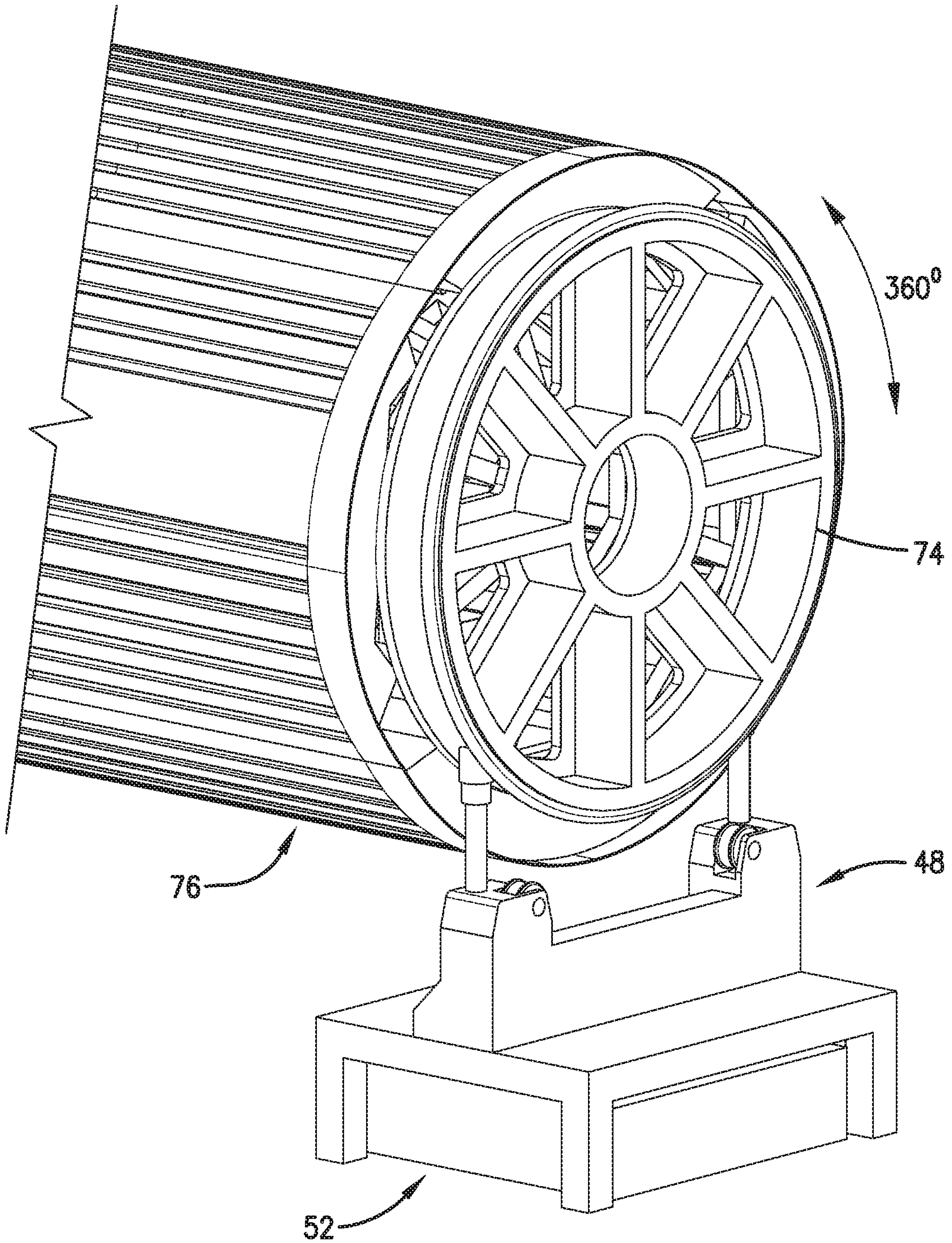


Fig. 5.

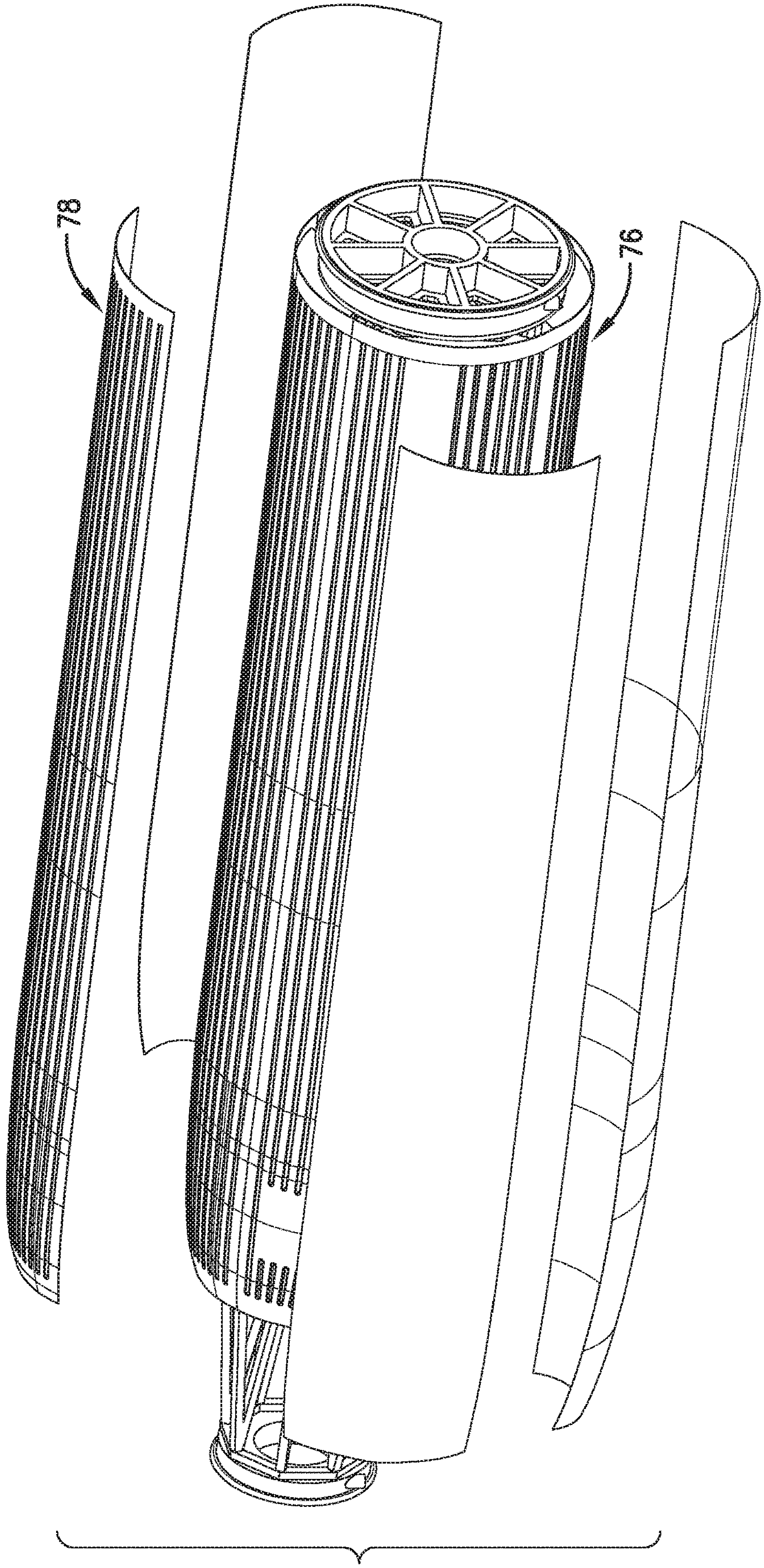


Fig. 6.

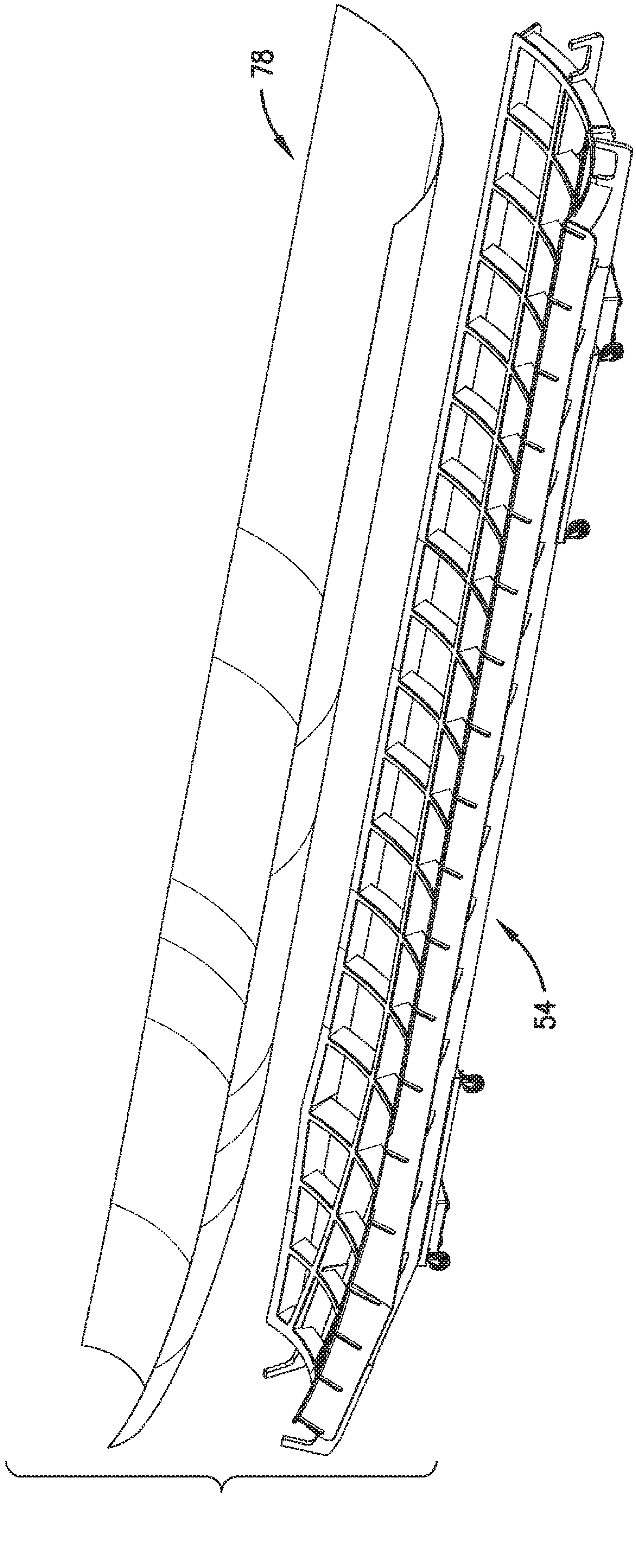


Fig. 7.

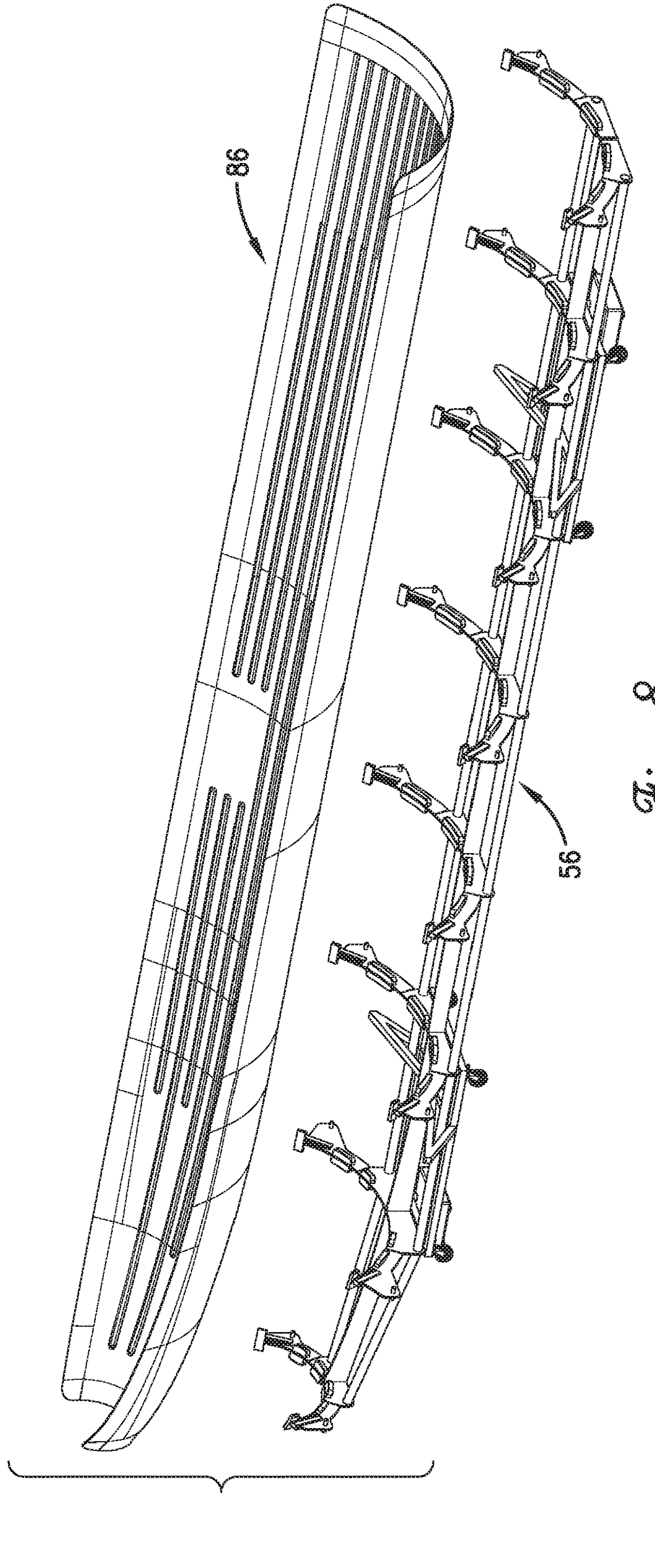


Fig. 8.

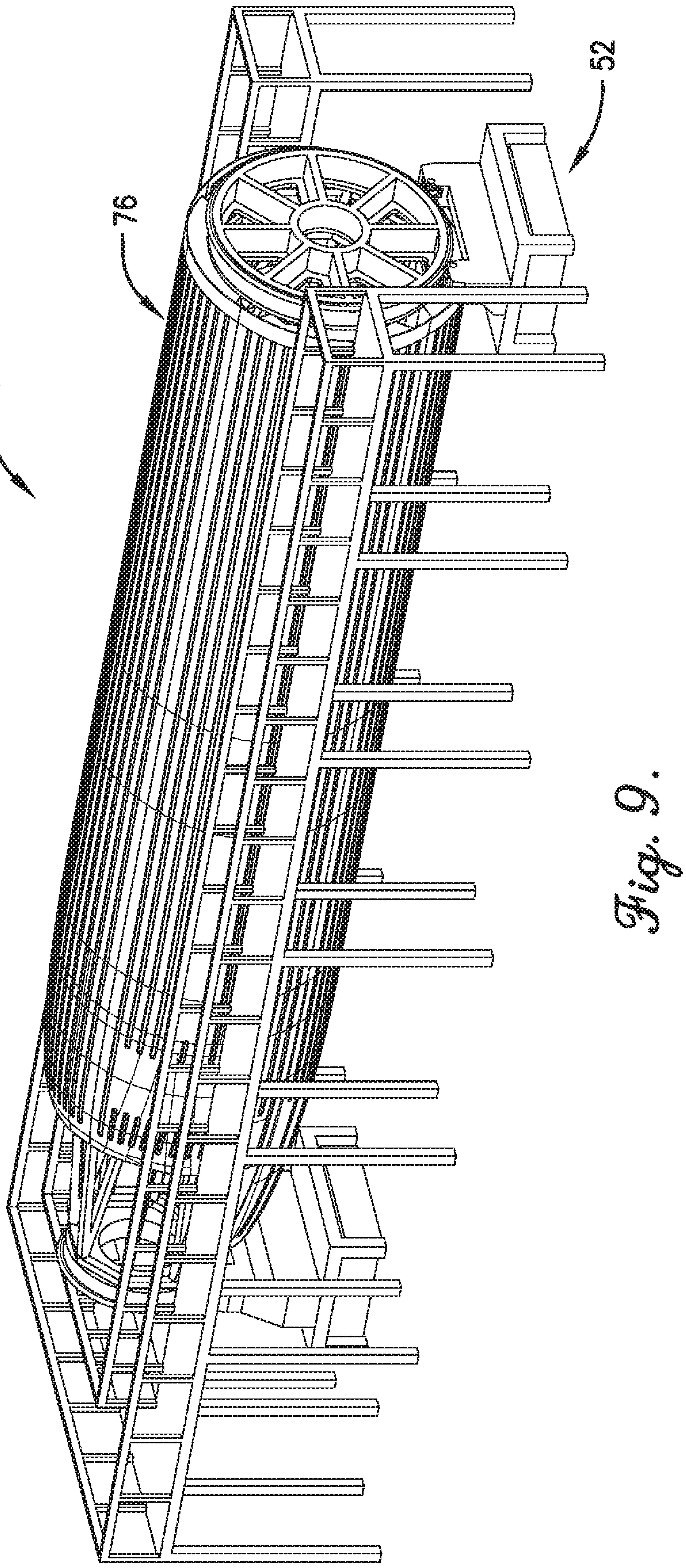


Fig. 9.

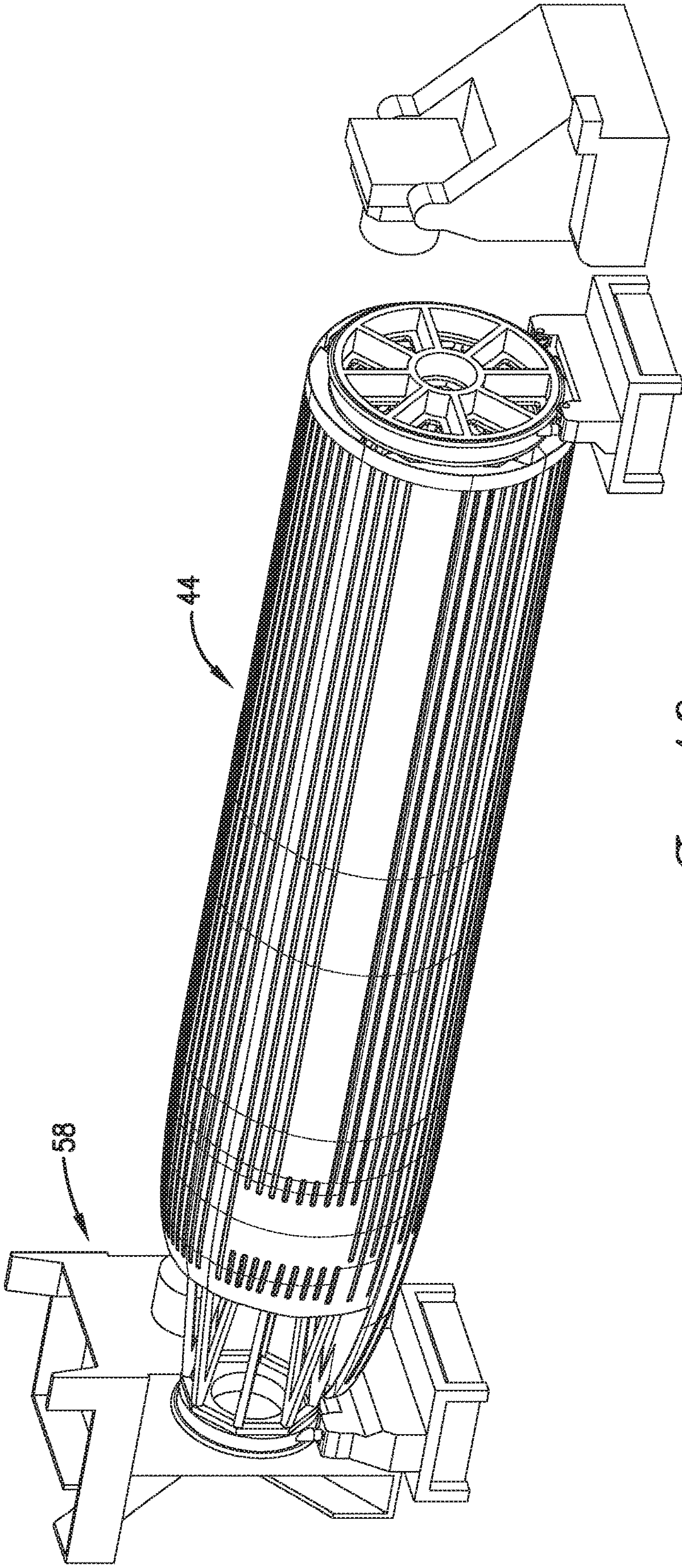


Fig. 10.

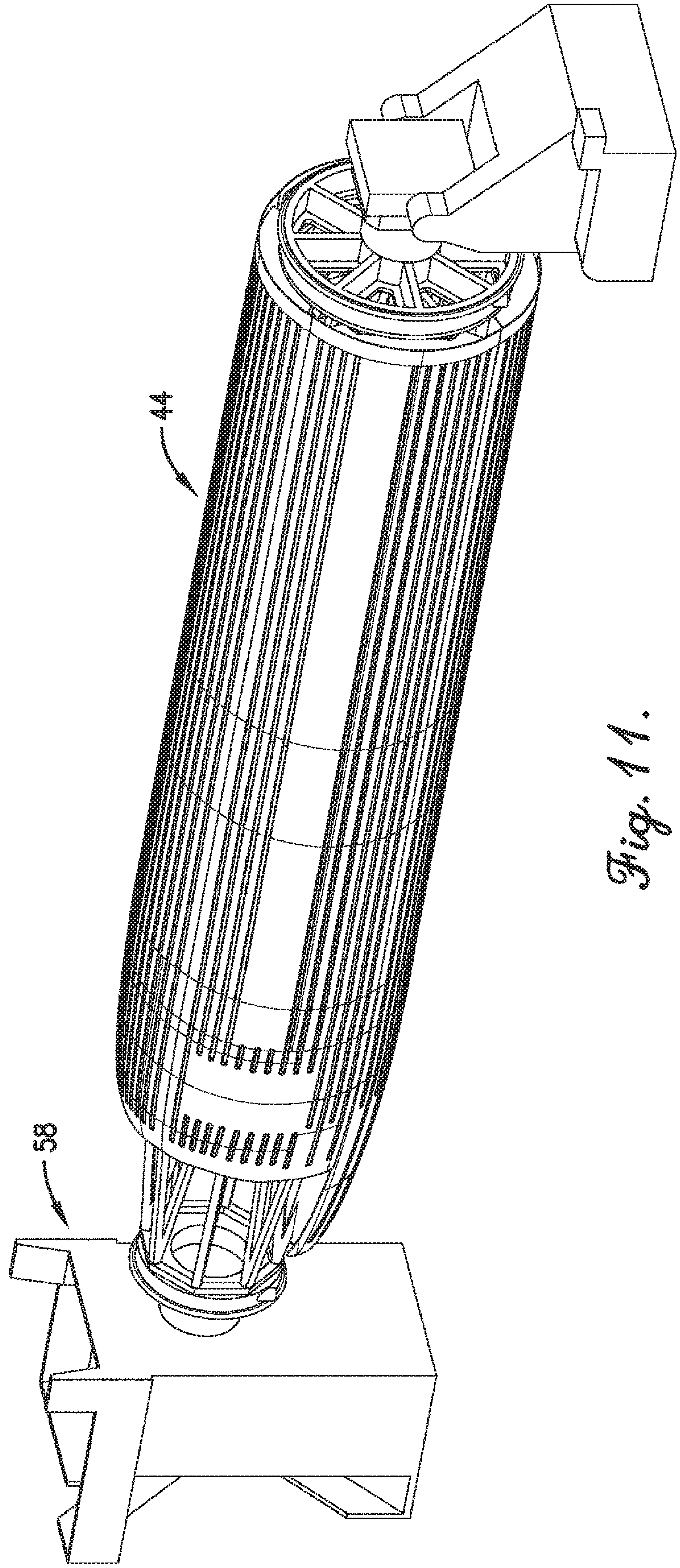


Fig. 11.

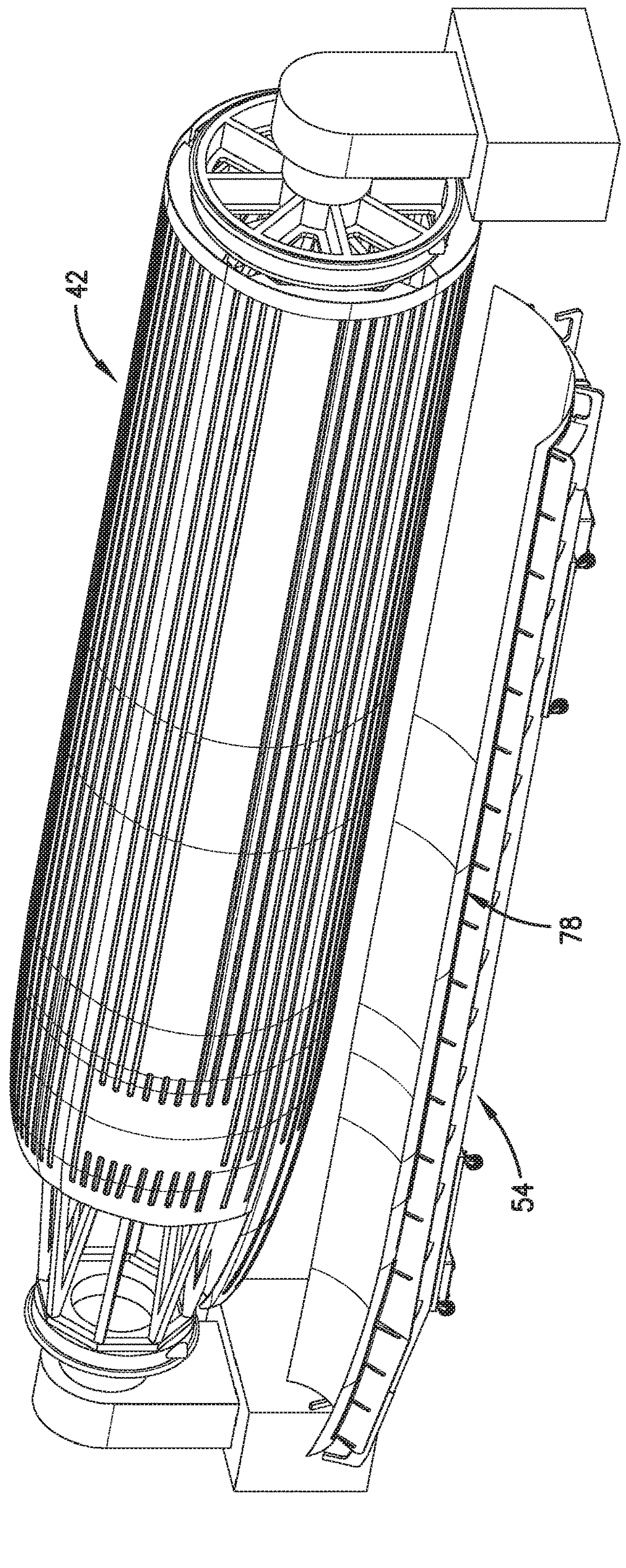


Fig. 12.

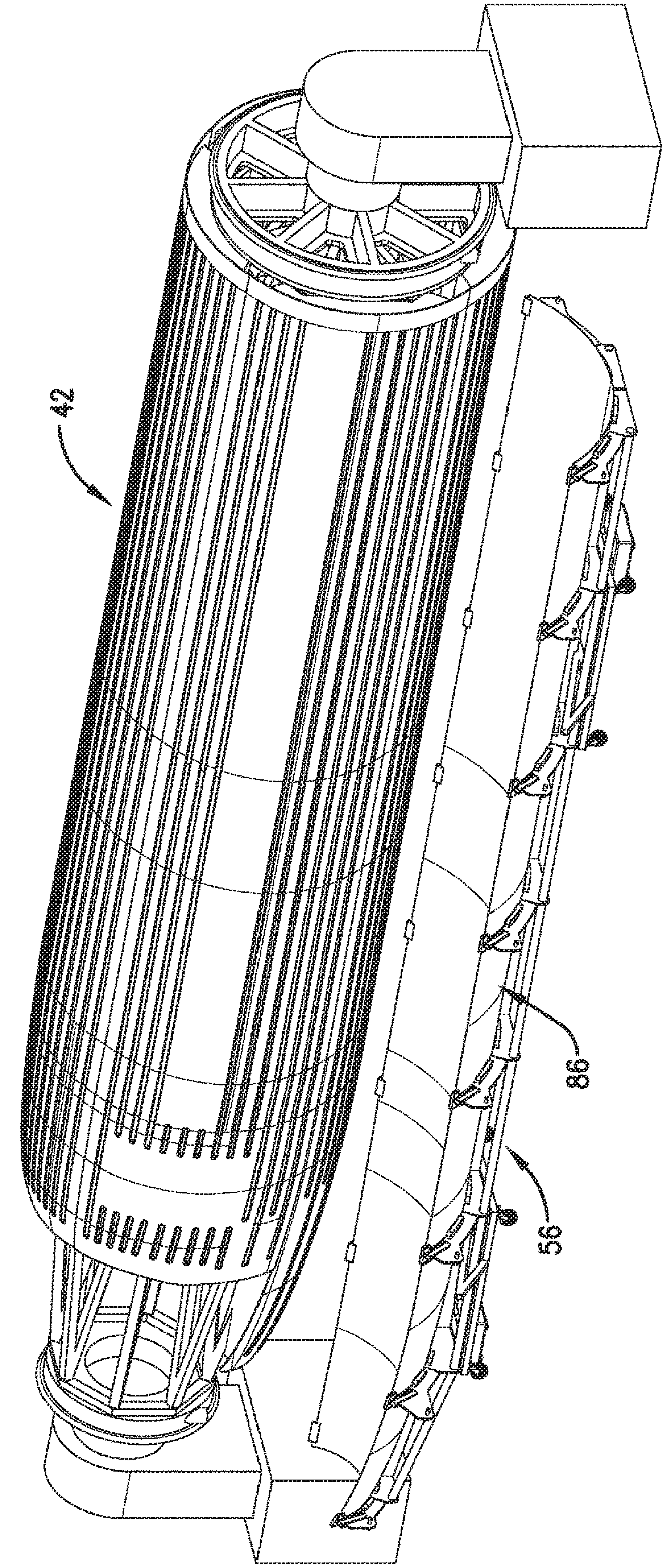


Fig. 13.

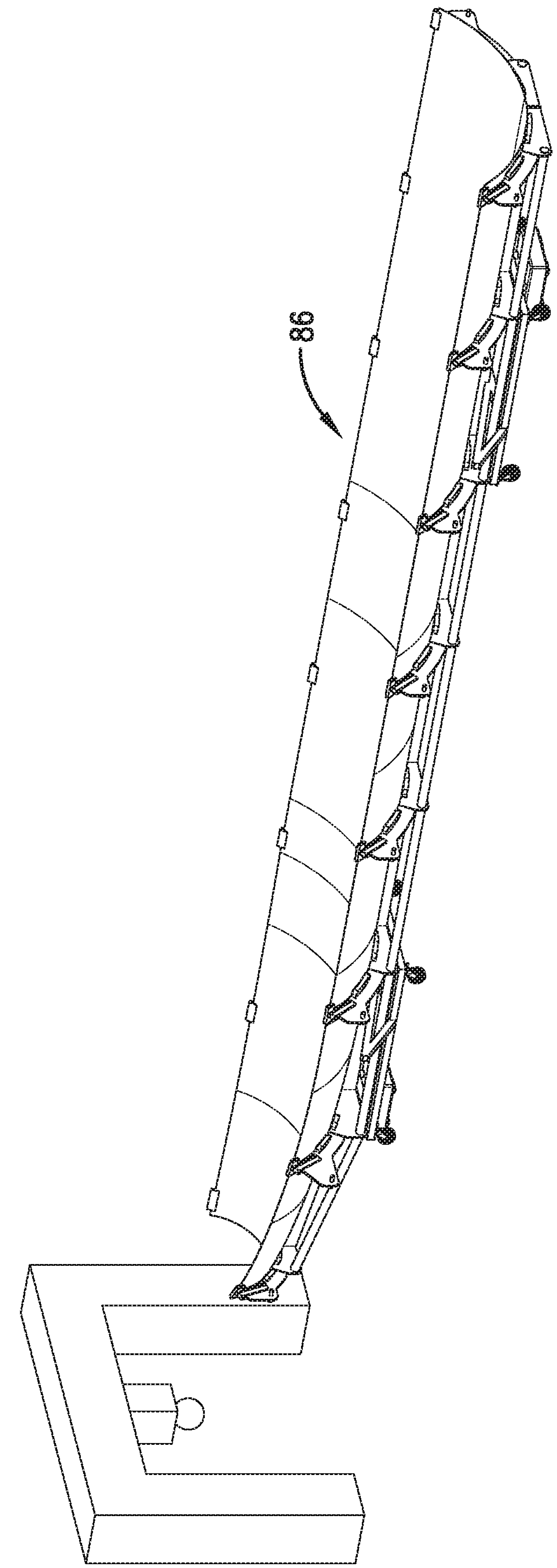


Fig. 14.

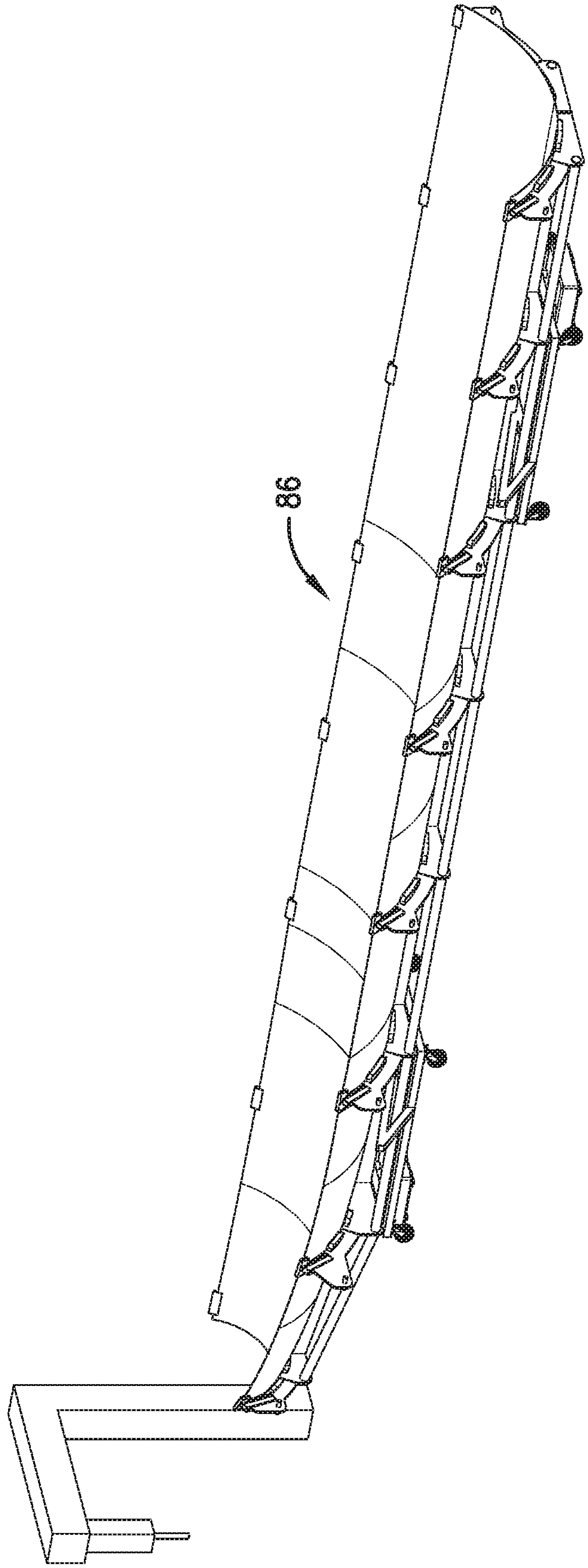


Fig. 15.

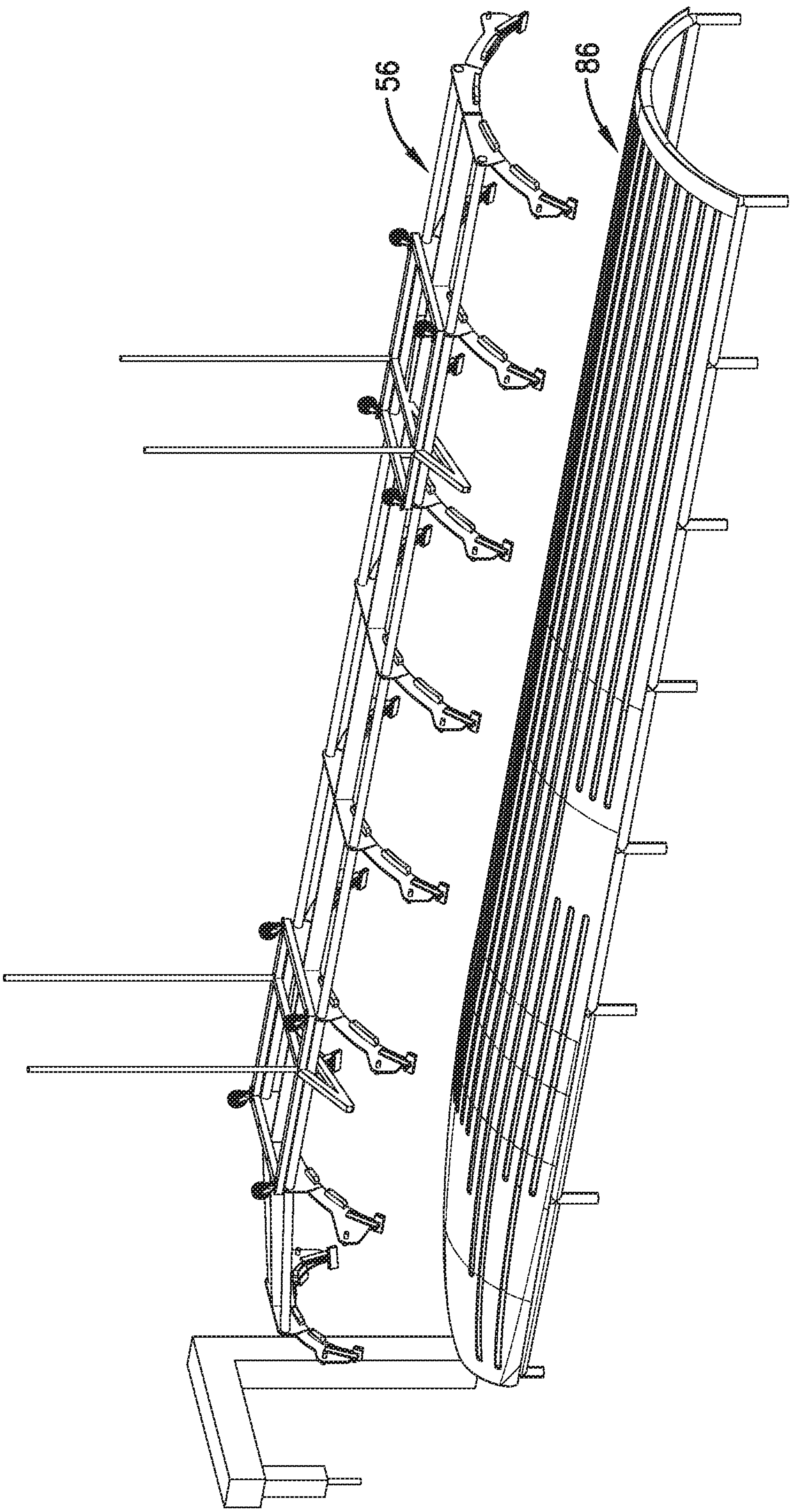


Fig. 16.

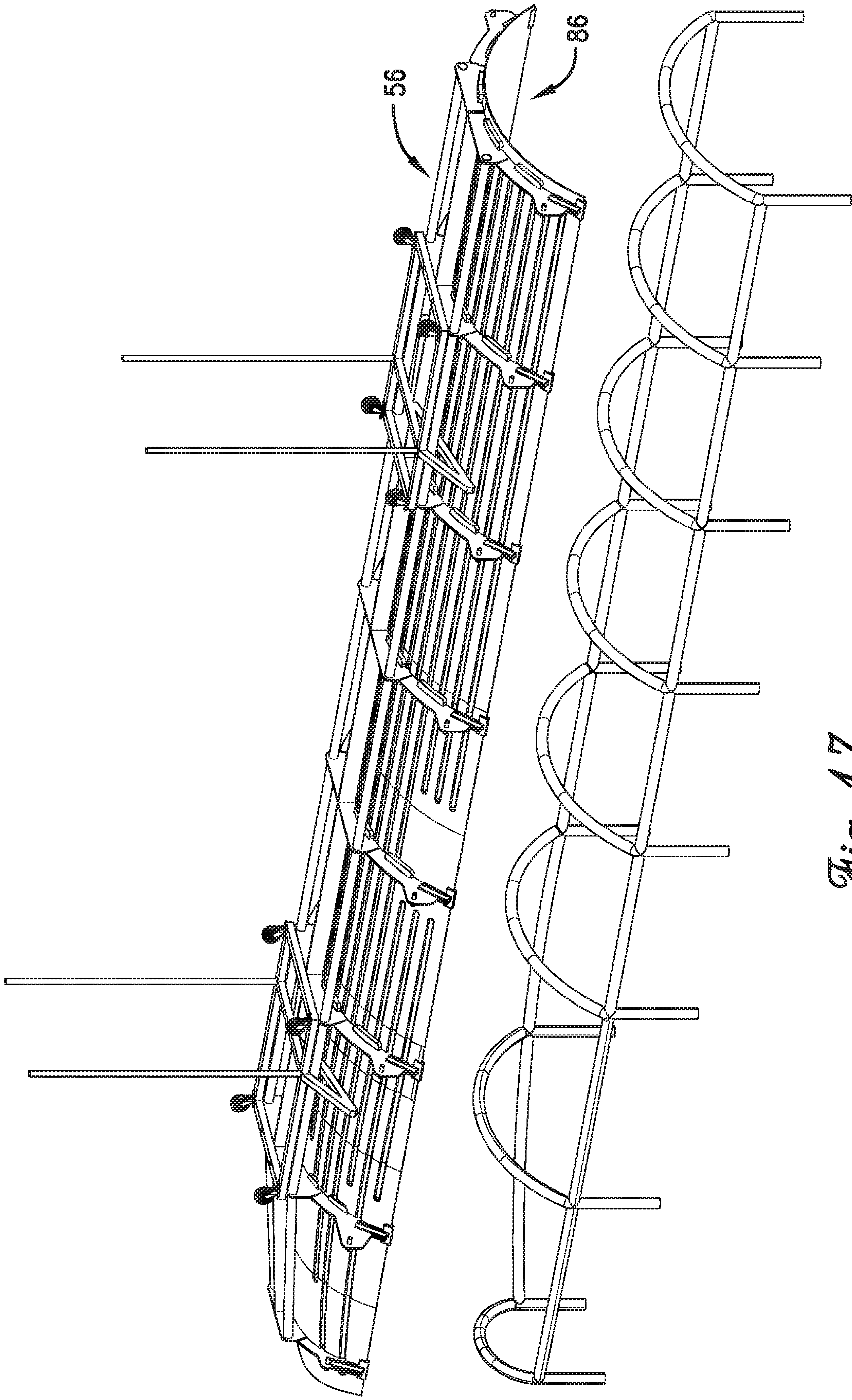


Fig. 17.

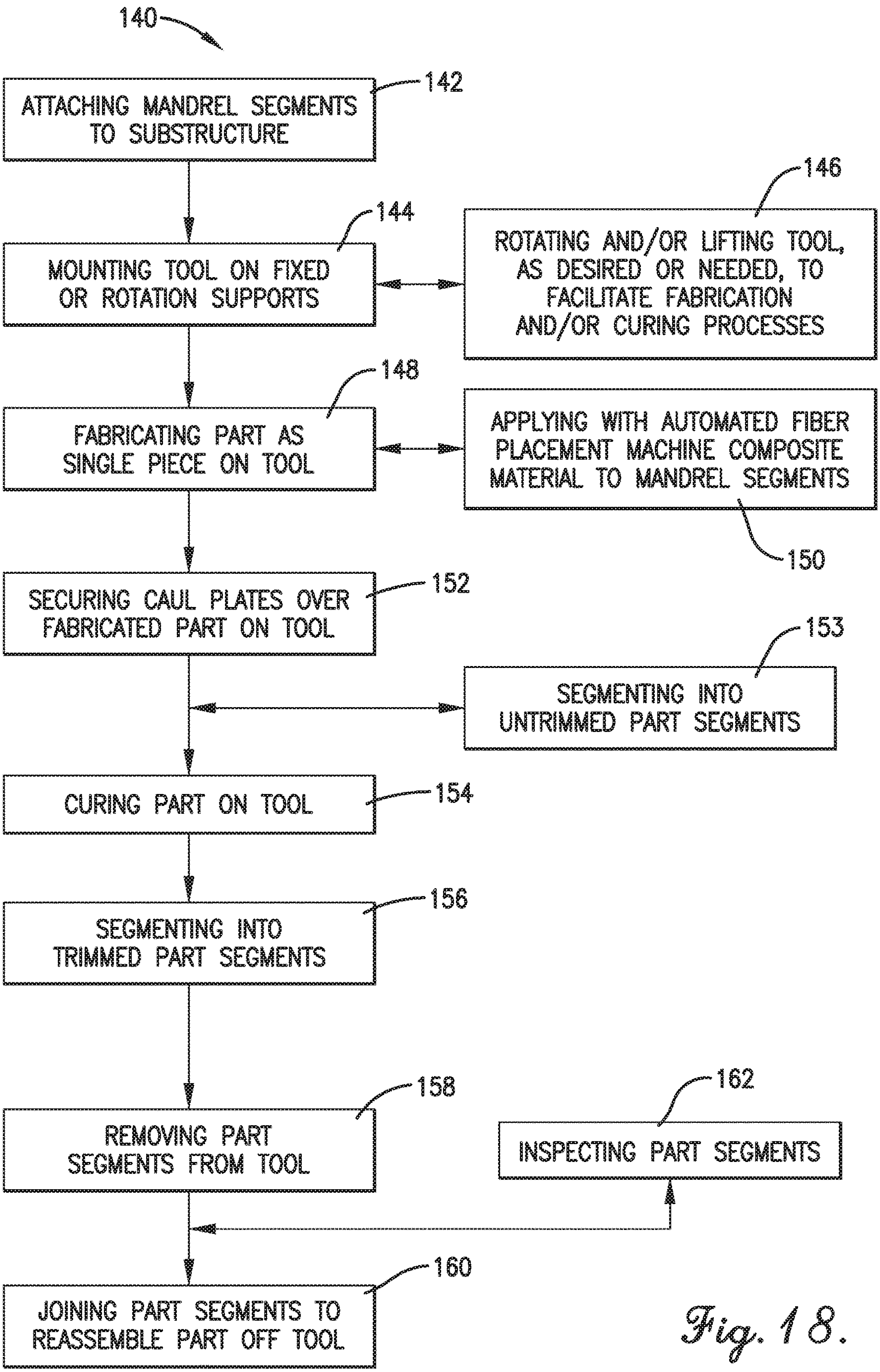

140
142
ATTACHING MANDREL SEGMENTS TO SUBSTRUCTURE
144
MOUNTING TOOL ON FIXED OR ROTATION SUPPORTS
146
ROTATING AND/OR LIFTING TOOL, AS DESIRED OR NEEDED, TO FACILITATE FABRICATION AND/OR CURING PROCESSES
148
FABRICATING PART AS SINGLE PIECE ON TOOL
APPLYING WITH AUTOMATED FIBER PLACEMENT MACHINE COMPOSITE MATERIAL TO MANDREL SEGMENTS
150
152
SECURING CAUL PLATES OVER FABRICATED PART ON TOOL
153
SEGMENTING INTO UNTRIMMED PART SEGMENTS
154
CURING PART ON TOOL
156
SEGMENTING INTO TRIMMED PART SEGMENTS
158
REMOVING PART SEGMENTS FROM TOOL
162
INSPECTING PART SEGMENTS
160
JOINING PART SEGMENTS TO REASSEMBLE PART OFF TOOL

Fig. 18.

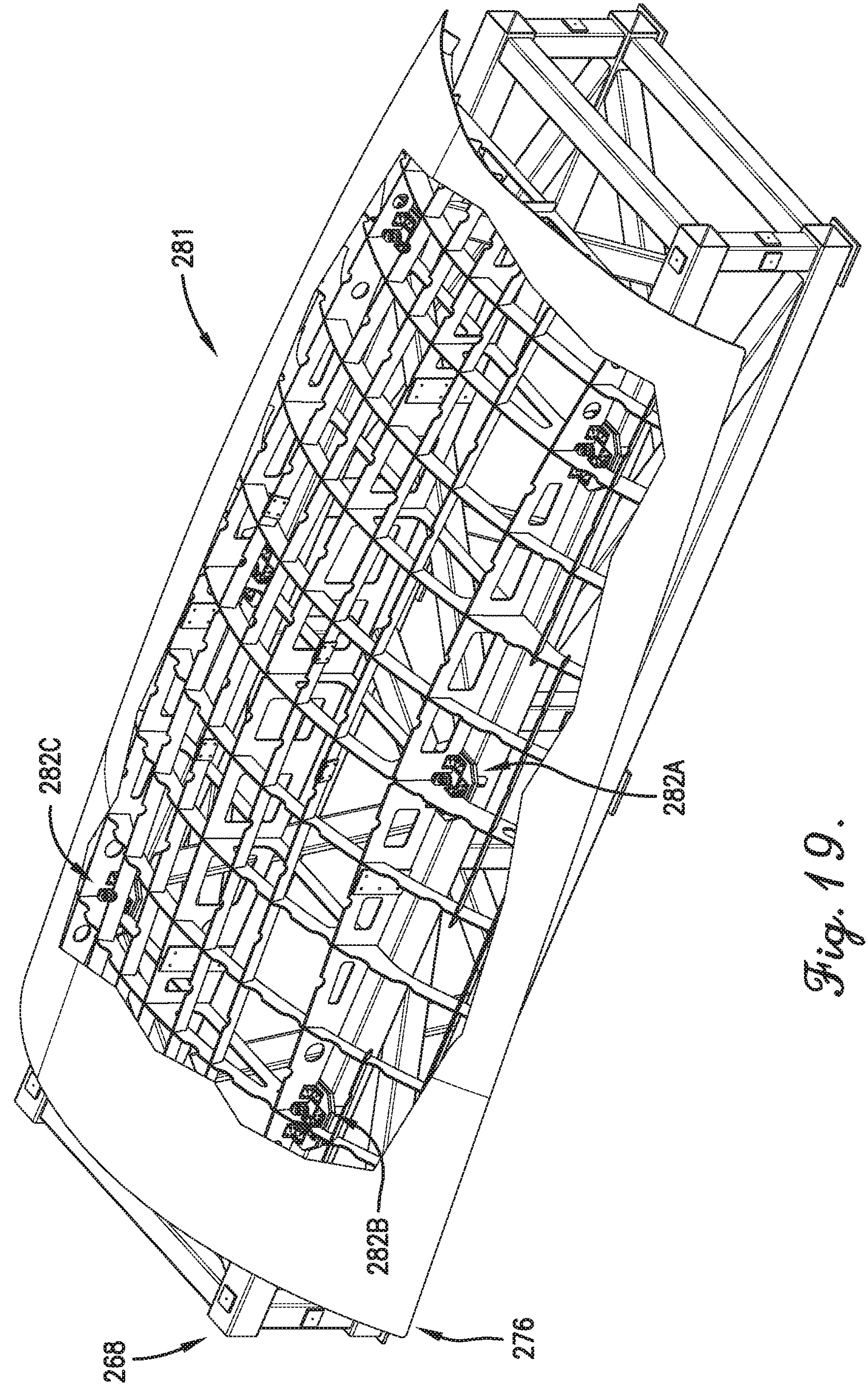


Fig. 19.

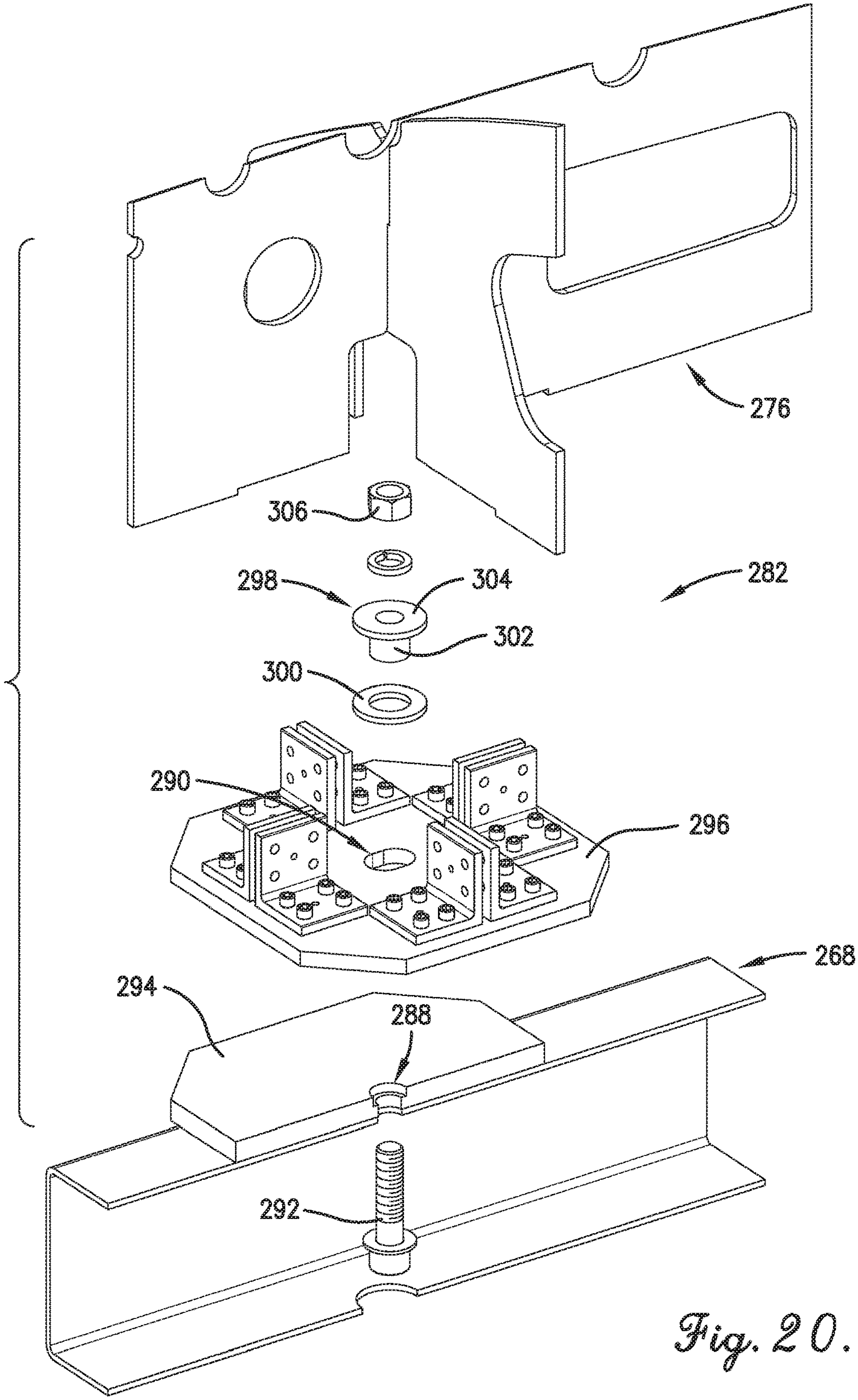


Fig. 20.

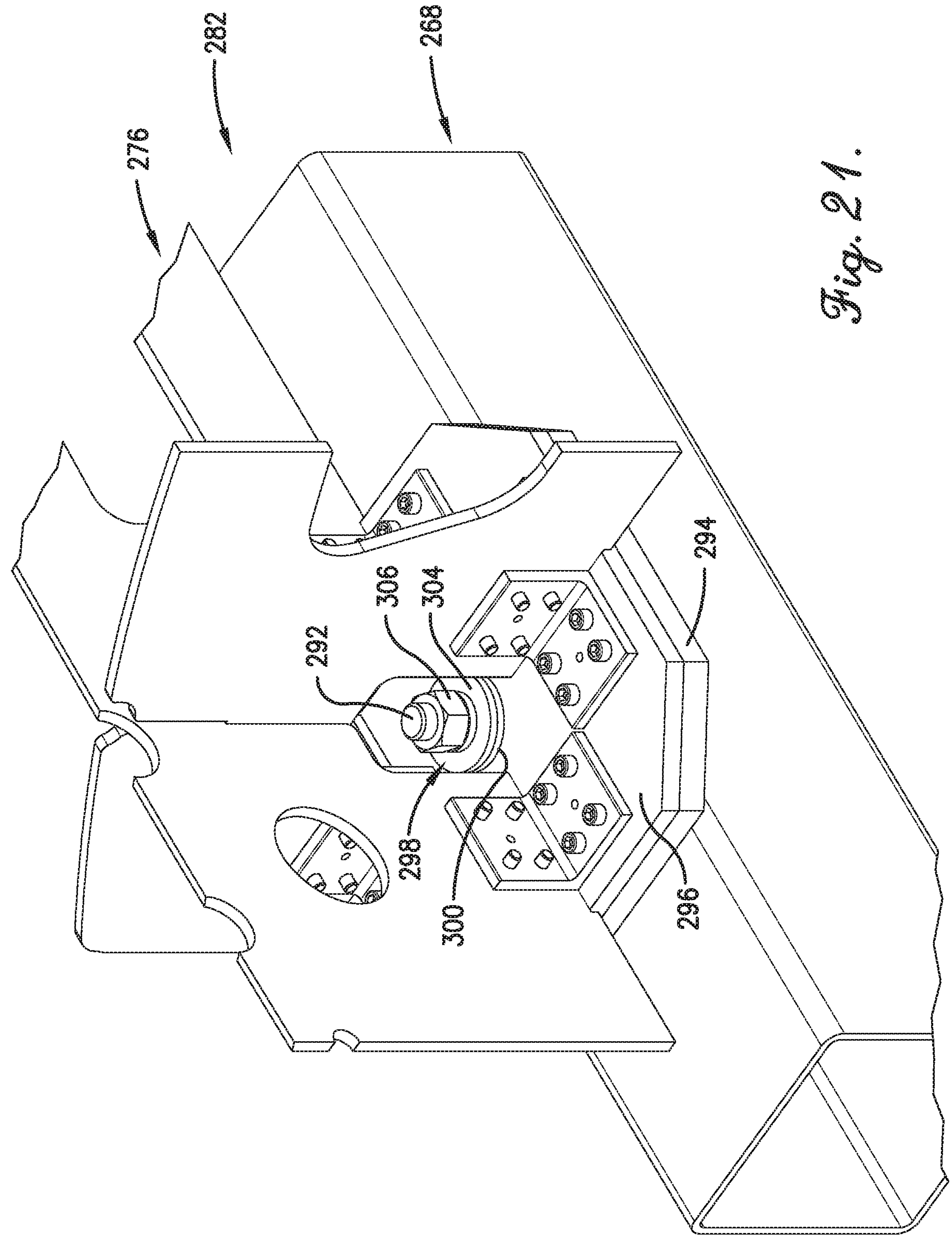


Fig. 21.

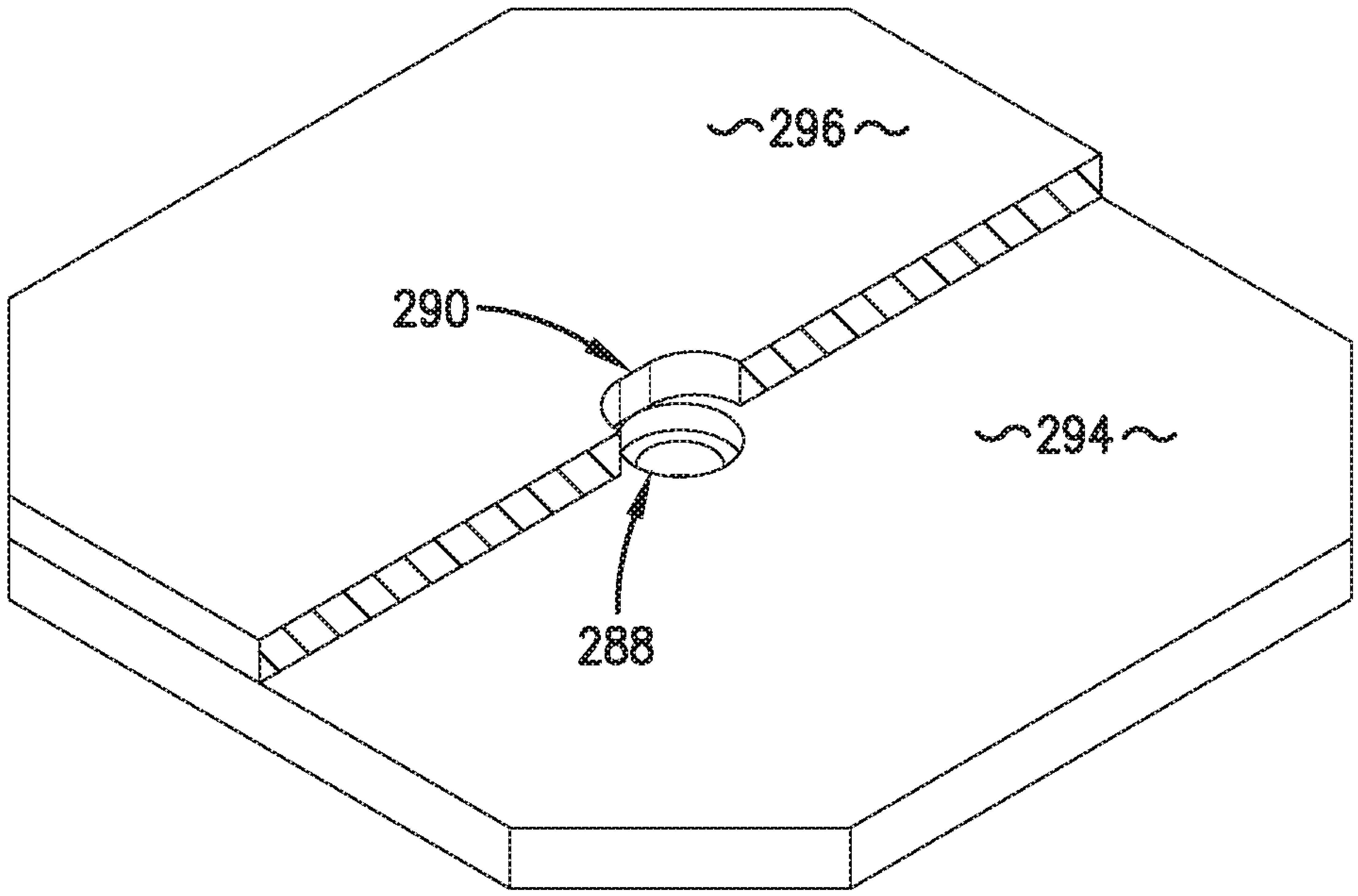


Fig. 22.

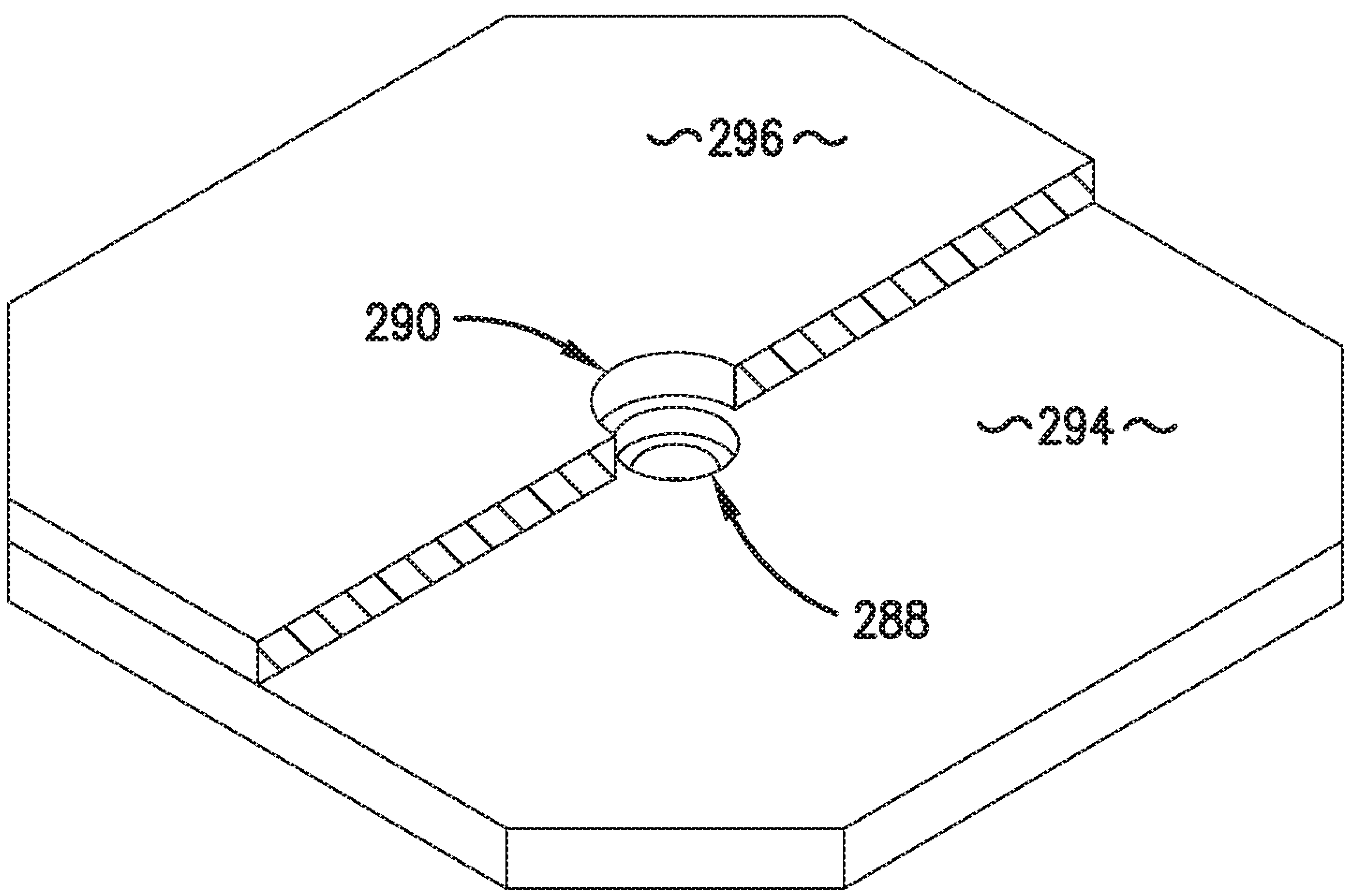


Fig. 23.

SYSTEM AND METHOD FOR FABRICATING AND CURING LARGE COMPOSITE STRUCTURES

RELATED APPLICATION

The present U.S. non-provisional patent application is a continuation-in-part and claims priority benefit of a prior-filed U.S. non-provisional patent application having the same title, Ser. No. 16/525,772, filed Jul. 30, 2019. The entire content of the identified prior-filed application is hereby incorporated by reference as if fully set forth herein.

FIELD

The present invention relates to systems and methods for fabricating and curing large composite structures, and more particularly, embodiments concerns a system and method for fabricating and curing large composite aircraft, aerospace, or other vehicle fuselages, bodies, or other part structures.

BACKGROUND

The fabrication and curing of large composite structures, such as aircraft fuselages, is a complex process involving tools which physically support the composite materials until the composite materials are at least partially cured. One solution is to fabricate and cure a plurality of independent part segments on different supportive tools, and then assemble the part segments to form the structure. However, this method suffers from several problems and limitations, including that the independent fabrication of the parts requires either that the parts be fabricated and cured one at a time, which is inefficient, or that multiple fabrication machines be provided and maintained, which is costly.

Another solution is to fabricate such a structure as a single piece on a large tool and then disassemble and remove the tool from within the fabricated and cured structure. However, this method also suffers from several problems and limitations, including that the tool must be designed to be disassembled into sufficiently small subcomponents so as to be removable through whatever opening remains in the fabricated and cured structure. Further, the processes of assembling and disassembling so many small tool subcomponents is time-consuming and inefficient.

This background discussion is intended to provide information related to the present invention which is not necessarily prior art.

SUMMARY

Embodiments address the above-described problems and limitations in the prior art by providing a system and method for fabricating and curing large composite aircraft, aerospace, or other vehicle fuselages, bodies, or other part structures, wherein the composite part is at least partially fabricated and cured on a tool, cut or otherwise segmented to facilitate removing it from the tool, removed from the tool without disassembling the tool, and then reassembled off the tool to reform the large composite part.

In a first embodiment, a system is provided for fabricating and curing a large composite part. The system may include a tool, an automated fiber placement machine, a curing mechanism, a cured material cutting mechanism, and a reassembly mechanism. The tool may be configured to support the large composite structure during the fabrication and curing processes, and may include a substructure and

one or more mandrel segments removably attached to the substructure and providing a surface on which the large composite part may be fabricated. The automated fiber placement machine may be configured to apply composite material comprising resin and synthetic fibers onto the mandrel segments to fabricate the large composite part as a single piece on the tool. The curing mechanism may be configured to cure the composite material on the mandrel segments to cure the large composite part on the tool. The cured material cutting mechanism may be configured to cut the large composite part on the tool into a plurality of trimmed part segments which may then be removed from the tool without disassembling the tool. The reassembly mechanism may be configured to join the plurality of trimmed part segments to reassemble the large composite part off the tool.

In various implementations, the first embodiment may include any one or more of the following additional features. The tool may include a plurality of the mandrel segments, and the system may further include an uncured material cutting mechanism configured to cut the large composite part on the tool into a plurality of untrimmed part segments prior to the curing process. The large composite structure may be an aircraft fuselage which has a length of at least five meters. The substructure may be constructed of a first material having a first coefficient of thermal expansion and the mandrel segments may be constructed of a second material having a second coefficient of thermal expansion which is lower than the first coefficient of thermal expansion, and the mandrel segments may be fixedly attached to the substructure at at least one location and movably attached to the substructure at at least one other location. The mandrel segments may include structure features configured to create corresponding structure components in the large composite part. The mandrel segments may include grooves configured to accommodate the cutting mechanism when cutting the large composite part into the trimmed part segments. The mandrel segments may include joining features configured to create corresponding joining components in the trimmed part segments which facilitate joining the trimmed part segments to reassemble the large composite part. The curing mechanism may include an autoclave, the cured material cutting mechanism may include a cutting disc, and the reassembly mechanism may include a fastener gun. The system may further include a center hub extending through a longitudinal axis of the substructure, a first interface element coupled with a first end of the center hub and a second interface element coupled with a second end of the center hub, and a rotation mechanism coupled with the interface elements and configured to allow the tool to be rotated about the longitudinal axis. The system may further include one or more caul plates configured to be secured over the composite material on the mandrel segments prior to curing the composite material.

In a second embodiment, a method is provided for fabricating and curing a large composite part. The method may include the following steps. The large composite structure may be supported with a tool during the fabrication and curing processes, and the tool may include a substructure and one or more mandrel segments removably attached to the substructure and providing a surface on which the large composite part may be fabricated. A composite material comprising resin and synthetic fibers may be applied onto the mandrel segments with an automated fiber placement machine to fabricate the large composite part as a single piece on the tool. The composite material may be cured on the mandrel segments with a curing mechanism to cure the large composite part on the tool. The large composite part may be cut on the tool with a cured material cutting mechanism into a plurality of trimmed part segments which may then be removed from the tool without disassembling the tool. The plurality of trimmed part segments may be reassembled with a reassembly mechanism to reassemble the large composite part off the tool.

In various implementations, the second embodiment may include any one or more of the following features. The tool may include a plurality of the mandrel segments, and the method may further include cutting with an uncured material cutting mechanism the large composite part on the tool into a plurality of untrimmed part segments prior to the curing process. The large composite structure may be an aircraft fuselage which has a length of at least five meters. The substructure may be constructed of a first material having a first coefficient of thermal expansion and the mandrel segments may be constructed of a second material having a second coefficient of thermal expansion which is lower than the first coefficient of thermal expansion, and the mandrel segments may be fixedly attached to the substructure at at least one location and movably attached to the substructure at at least one other location. The mandrel segments may include structure features configured to create corresponding structure components in the large composite part. The mandrel segments may include grooves configured to accommodate the cured material cutting mechanism when cutting the large composite part into the trimmed part segments. The mandrel segments may include joining features configured to create corresponding joining components in the plurality of trimmed part segments which facilitate joining the trimmed part segments to reassemble the large composite part. The curing mechanism may include an autoclave, the cured material cutting mechanism may include a cutting disc, and the reassembly mechanism may include a fastener gun. The method may further include a center hub extending through a longitudinal axis of the substructure, a first interface element coupled with a first end of the center hub and a second interface element coupled with a second end of the center hub, and a rotation mechanism coupled with the interface elements and configured to allow the tool to be rotated about the longitudinal axis. The method may further include securing one or more caul plates over the composite material on the mandrel segments prior to curing the composite material.

This summary is not intended to identify essential features of the present invention, and is not intended to be used to limit the scope of the claims. These and other aspects of the present invention are described below in greater detail.

DRAWINGS

Embodiments of the present invention are described in detail below with reference to the attached drawing figures, wherein:

FIG. **1** is a depiction of an embodiment of a system engaged in a process of at least partially fabricating and curing a large composite structure;

FIG. **2** is an exploded perspective view of certain components of the system of FIG. **1**;

FIG. **3** is an exploded perspective view of certain components of a tool component of the system of FIG. **1**;

FIG. **4** is a perspective view of the tool component mounted on rotating support mechanisms and guided vehicle components of the system of FIG. **1**;

FIG. **5** is a fragmentary perspective view of the rotating support components rotating and/or lifting the tool component;

FIG. **6** is an exploded perspective view of caul plate components of the system of FIG. **1**;

FIG. **7** is an exploded perspective view of a mandrel segment and caul plate handling mechanism component of the system of FIG. **1**;

FIG. **8** is an exploded perspective view of a part segment handling mechanism component of the system of FIG. **1**;

FIG. **9** is a perspective view of the tool component being assembled;

FIG. **10** is a perspective view of the tool component being transported to an automated fiber placement machine component of the system of FIG. **1**;

FIG. **11** is a perspective view of the tool component mounted on the automated fiber placement machine component for fabrication of the part;

FIG. **12** is a perspective view of the caul plate component being secured over the part prior to curing;

FIG. **13** is a perspective view of a part segment being removed from the tool component following curing and cutting of the part;

FIG. **14** is a perspective of the part segment being trimmed and/or drilled;

FIG. **15** is a perspective view of the part segment undergoing inspection of an inner mold line;

FIG. **16** is a perspective view of the part segment undergoing inspection of an outer mold line;

FIG. **17** is a perspective view of the part segment being positioned for reassembly with other part segments to reform the large composite structure;

FIG. **18** is a flowchart of an embodiment of a method of at least partially fabricating and curing a large composite structure;

FIG. **19** is a cutaway isometric view of a mounting system which may be used with the tool component or a version thereof to attach the mandrel segment to a substructure, wherein portions of a facesheet of the mandrel segment are shown cut away to reveal details underneath;

FIG. **20** is a fragmentary exploded isometric view of an attachment mechanism component of the mounting system;

FIG. **21** is a fragmentary isometric view of the attachment mechanism of FIG. **20**;

FIG. **22** is a fragmentary isometric view of a configuration of openings in an implementation of a directional type of the attachment mechanism of FIG. **21**; and

FIG. **23** is a fragmentary isometric view of a configuration of openings in an implementation of a non-directional type of the attachment mechanism of FIG. **21**.

The figures are not intended to limit the present invention to the specific embodiments they depict. The drawings are not necessarily to scale.

DETAILED DESCRIPTION

The following detailed description of embodiments of the invention references the accompanying figures. The embodiments are intended to describe aspects of the invention in sufficient detail to enable those with ordinary skill in the art to practice the invention. Other embodiments may be utilized and changes may be made without departing from the scope of the claims. The following description is, therefore, not limiting. The scope of the present invention is defined only by the appended claims, along with the full scope of equivalents to which such claims are entitled.

In this description, references to “one embodiment,” “an embodiment,” or “embodiments” mean that the feature or features referred to are included in at least one embodiment of the invention. Separate references to “one embodiment,” "an embodiment," or "embodiments" in this description do not necessarily refer to the same embodiment and are not mutually exclusive unless so stated. Specifically, a feature, component, action, step, etc. described in one embodiment may also be included in other embodiments, but is not necessarily included. Thus, particular implementations of the present invention can include a variety of combinations and/or integrations of the embodiments described herein.

Embodiments provide a system and method for fabricating large composite aircraft, aerospace, or other vehicle fuselages, bodies, or other part structures, wherein the composite part is at least partially fabricated and cured on a tool, cut or otherwise segmented to facilitate removing it from the tool, removed from the tool without disassembling the tool, and then reassembled off the tool to reform the large composite part. As used herein, a "large" part shall mean a part which is, in various implementations, at least five meters, or at least ten meters, or at least fifteen meters in at least one dimension. For example, the large composite structure may be a generally cylindrical aircraft fuselage which is at least five meters in length along a longitudinal axis.

An embodiment of such a system for fabricating a large composite aircraft, aerospace, or other vehicle fuselage, body, or other part may include a tool having a substructure and one or more mandrel segments removably attachable to the substructure. The substructure may be configured to physically and operationally support the mandrel segments during fabrication and curing of the part. The substructure may have substantially any suitable design and shape as may be desired or required for a particular application. In one implementation, in which the part to be fabricated is a generally cylindrical aircraft fuselage, the substructure may be generally cylindrically shaped, while in other implementations, the substructure may be, for example, geometrically or irregularly shaped. The substructure may be constructed of substantially any suitable material, such as metal or composite. In one implementation, the substructure may include a hub extending along a longitudinal axis C through the substructure, and first and second interface elements coupled with opposite ends of the hub and configured to allow for mounting the substructure on rotatable or fixed and/or movable structures to facilitate the fabrication, curing, and/or removal of the part.

The mandrel segments may be configured to physical and operationally support the part during fabrication and curing of the part. The mandrel segments may have substantially any suitable design and shape as may be desired or required for a particular application. The mandrel segments may include structure features configured to create corresponding structure components in the fabricated part. In one implementation, there may a single mandrel segment, while in other implementations, there may be any number of mandrel segments (e.g., between two and ten, or between two and four) as may be desired or required for a particular application. In one implementation, the mandrel segments may be substantially similar or even identical, while in other implementations, one or more of the mandrel segments may differ significantly in size and/or shape from the other mandrel segments. In one implementation, in which the part to be fabricated is a generally cylindrical aircraft fuselage, a single mandrel segment may be generally cylindrically shaped, while multiple mandrel segments may be generally curved so as to fit together on the substructure to form a generally cylindrical shape.

The one or more mandrel segments may be constructed of substantially any suitable material, such as composite such has bismaleimide or other high temperature resin and carbon fiber, Kevlar, fiberglass, or other synthetic fibers. In one implementation, the substructure and the mandrel segments may be constructed of the same or relevantly similar materials and have significantly the same or the same expansion and contraction characteristics and/or other relevant characteristics, while in other implementations, they may be constructed of relevantly different materials and have different expansion and contraction characteristics or other relevant characteristics. For example, in one implementation, the substructure may be constructed from steel having a relatively high coefficient of thermal expansion, and the mandrel segments may be constructed from composite or an iron-nickel alloy such as Invar having a relatively low coefficient of thermal expansion. In such a case, the mandrel segments may be fixedly attached to the substructure at at least one location and movably attached to the substructure at at least one other location with slip joints or other movable attachment mechanisms to allow the mandrel segments to "float" on the substructure and thereby accommodate differential expansion and contraction movement or other relative movement of the mandrel segments and the substructure (such as while being heated to cure the part).

In one implementation, the mandrel segments may be provided with grooves to accommodate a cutting mechanism to facilitate cutting the part along defined lines in order to remove the part from the tool. In various implementations, the part may be cut or otherwise segmented into untrimmed segments prior to curing and/or cut or otherwise segmented into trimmed segments after curing, while remaining on the tool. In one implementation, the resulting part segments may be reassembled off the tool by being butt-joined together, while in other implementations, the mandrel segments may be configured to shape the part segments to facilitate reassembly. For example, the mandrel segments may be configured to impart joggle structures or other joining structures to create joining components which facilitate joining the part segments together to reform the large composite part.

In one implementation, the system may further include one or more caul plates configured to be positioned on the fabricated part prior to curing to produce a smoother finish for the cured part.

An embodiment of a method for fabricating the large composite aircraft, aerospace, or other vehicle fuselage, body, or other part may include the following steps. In one implementation, the method may employ some or all of the components of the above-described system. The tool may be assembled by attaching the one or more mandrel segments to the substructure. The part may be at least partially fabricated as a single piece on the tool (using, e.g., automated fiber placement technology). If used, the one or more caul plates may be secured (by, e.g., vacuum bagging) over the fabricated part. In one implementation, the part may be cut or otherwise segmented into untrimmed segment prior to curing. The part may be at least partially cured (by, e.g., autoclaving) on the tool. The at least partially fabricated and cured part may be cut or otherwise segmented into a plurality of trimmed part segments prior to removal from the tool. The part segments may be removed from the tool without disassembling the tool. The part segments may be reassembled to reform the large composite part.

Referring to FIGS. **1-17**, an example implementation of the above-described system **40** is shown adapted for fabricating a large generally cylindrical composite fuselage part **42** for an aircraft, wherein the composite fuselage is at least partially fabricated and cured on the tool **44**, cut or otherwise segmented to facilitate removing it from the tool **44** without disassembling the tool **44**, removed from the tool **44**, and then reassembled off the tool **44** to reform the large composite fuselage **42**. The system **40** may include the tool **44**, first and second rotation support mechanisms **48**, one or more fixed support mechanisms **50**, one or one or more guided vehicles **52**, one or more mandrel segment and caul plate handling mechanisms **54**, one or more part segment handling mechanisms **56**, an automated fiber placement machine **58**, an uncured material cutting mechanism **59**; a curing mechanism **60**, a cured material cutting mechanism **62**, and a reassembly mechanism **64**.

The tool **44** may be configured to physically and operationally support the part **42** during fabrication and curing. In particular, the tool **44** may be moveable and positionable to facilitate fabricating the part **42** using the automated fiber placement machine **58**, and may be further moveable and positionable, with the fabricated part **42** thereon, to facilitate curing the part **42** using the curing mechanism **60**. Referring particularly to FIG. **3**, the tool **44** may include a substructure **68**, a central hub **70** and first and second interface rings **72**,**74** attached to opposite ends of the hub **70**, one or more mandrel segments **76** removably attachable to the substructure **68**, and one or more caul plates **78**.

The substructure **68** may be configured to physically and operationally support the mandrel segments **76** during fabrication and curing of the part **42**. The substructure **68** may have substantially any suitable design and shape as may be desired or required for a particular application. In this example implementation, the part **42** to be fabricated is a generally cylindrical aircraft fuselage, so the substructure **68** may also be generally cylindrically shaped or, at least, otherwise elongated along the longitudinal axis C. The substructure **68** may be constructed of substantially any suitable material, such as metal or composite. In this example implementation, the substructure **68** may be constructed of steel.

The central hub **70** may extend through the substructure **68** along the longitudinal axis C and may be configured to physically and/or functionally cooperate with the interface rings **72**,**74** to facilitate supporting and/or rotating the substructure **68**. In one implementation, the central hub **70** may be configured to experience minimal deflection of approximately between 0.055 inches and 0.100 inches when loaded. The first and second interface rings **72**,**74** may physically and/or functionally cooperate with opposite ends of the central hub **70** and may be configured to facilitate mounting the substructure **68** on the rotating and/or fixed support mechanisms **48**,**50** to facilitate fabricating, curing, and/or removing the part **42**.

The mandrel segments **76** may be configured to physical and operationally support the part **42** during fabrication and curing of the part **42**. The mandrel segments **76** may have substantially any suitable design and shape as may be desired or required for a particular application. In this example implementation, the mandrel segments **76** may include surface features **80** configured to create corresponding components, such as stringers and/or other structural or operational features, in the fabricated part **42**.

In one implementation, there may a single mandrel segment **76**, while in other implementations, there may be any number of mandrel segments **76** (e.g., between two and ten, or between two and four) as may be desired or required for particular applications. In one implementation, the mandrel segments **76** may be substantially similar or even identical, while in other implementations, one or more of the mandrel segments **76** may differ significantly in size and/or shape from the other mandrel segments **76**. In this example implementation, there may between two and four, mandrel segments **76**, which are substantially similar in size and/or shape to each other, and which and are generally curved so that, when they are attached to the substructure **68**, they fit together to form the generally cylindrical shape of the fuselage part **42**.

The one or more mandrel segments **76** may be constructed of substantially any suitable material, such as a composite. In one implementation, the mandrel segment composite may include bismaleimide or other high temperature resin and carbon fiber, Kevlar, fiberglass, or other synthetic fibers. In one implementation, the substructure **68** and the mandrel segments **76** may be constructed of the same or relevantly similar materials and have the significantly the same or the same expansion and contraction characteristics and/or other relevant characteristics, while in other implementations, they may be constructed of relevantly different materials and have different expansion and contraction characteristics (i.e., different coefficients of thermal expansion) or other relevant characteristics. In this example implementation, each mandrel segment **76** may include a Pan board substructure and a bismaleimide composite surface.

In one implementation, the substructure **68** and the mandrel segments **76** may be constructed of the same or relevantly similar materials and have the significantly the same or the same expansion and contraction characteristics and/or other relevant characteristics, while in other implementations, they may be constructed of relevantly different materials and have different expansion and contraction characteristics or other relevant characteristics. In this example implementation, the substructure **68** is constructed from steel having a relatively high coefficient of thermal expansion, and the mandrel segments **76** are constructed from bismaleimide and graphite composite having a relatively low coefficient of thermal expansion. Thus, the mandrel segments **76** may be fixedly attached to the substructure **68** at at least one location and movably attached to the substructure **68** at at least one other location with slip joints or other movable attachment mechanisms **82** to allow the mandrel segments **76** to "float" on the substructure **68** and thereby accommodate differential expansion and contraction movement or other relative movement of the mandrel segments **76** and the substructure **68** (such as might occur during curing).

Referring also to FIGS. **19-23**, an embodiment of a mounting system **281** is shown configured to removably mount the mandrel segment **276** onto the substructure **268**. The mandrel segment **276** and the substructure **268** are physically distinct components which temporarily combine to facilitate steps in the process of fabricating and curing a large composite structure. As discussed, the material of the mandrel segment **276** may have a different coefficient of thermal expansion than the material of the substructure **268**. The mounting system **281** may include two or more attachment mechanisms **282** which allow the mandrel segment **276** to "float" on the substructure **268** and thereby accommodate movement due to differential expansion and contraction (such as might occur during curing) or other relative movement of the mandrel segment **276** and the substructure **268**.

Referring particularly to FIGS. **20** and **21**, each attachment mechanism **282** may broadly include a first opening **288** in the substructure **268** or in a plate or other piece welded, coupled, or otherwise physically associated or associatable with the substructure **268**, a second opening **290** in the mandrel segment **276** or in a plate or other piece coupled or otherwise physically associated or associatable with the mandrel segment **276**, and a bolt **292** extending through the first and second openings **288**,**290** and configured to secure the mandrel segment **276** to the substructure **268**.

At least one of the attachment mechanisms **282**A may be of a fixed type which provides a fixed point at which the mandrel segment **276** and the substructure **268** do not move relative to each other. For this fixed type of the attachment mechanism **282**A, the first and second openings **288**,**290** may be approximately identical in size.

At least one of the attachment mechanisms **282**B may be of a directional type which allows relative movement along a line in a direction (e.g., along an X or Y axis) between the mandrel segment **276** and the substructure **268**. As shown in FIG. **22**, for this directional type of the attachment mechanism **268**B, at least one of the first and second openings **288**,**290** may be elongated along the line in the direction. In one implementation, the mounting system **281** may include a plurality of the directional type attachment mechanisms **282**B, wherein some may allow relative movement in a first direction (e.g., along the X axis) and some may allow relative movement in a second direction (e.g., along a Y axis).

At least one of the attachment mechanisms **282**C may be of a non-directional type which allows relative movement on a plane in any direction between the mandrel segment **276** and the substructure **268**. As shown in FIG. **23**, for this non-directional type of the attachment mechanism **282**C, at least one of the first and second openings **288**,**290** may be oversized. In one implementation, the mounting system **281** may include a plurality of the non-directional type attachment mechanisms **282**C.

In various implementations, the mounting system **281** may include at least one fixed type attachment mechanism **282**A and at least one non-directional type attachment mechanism **282**C; at least one fixed, at least one directional, and at least one non-directional type attachment mechanisms **282**A,**282**B,**282**C; or at least one fixed type attachment mechanism **282**A, at least two directional type attachment mechanisms **282**B oriented in different directions, and at least two nondirectional type attachment mechanisms **282**C. In one implementation, the directional and non-directional attachment mechanisms **282**B,**282**C may be oriented such that the allowed relative movements are all co-planar.

In one implementation, each attachment mechanism **282** may include a first surface **294** welded to or otherwise physically associated with the substructure **268**, wherein the first opening **288** extends through the first surface **294**; a second surface **296** attachable to or otherwise physically associatable with the mandrel segment **276**, wherein the second opening **290** extends through the second surface **296**; and a bushing **298** and a washer **300** which fit over the bolt **292**. The first and second surfaces **294**,**296** may be plates made of steel or other metal. The bushing **298** may include a sleeve **302** and a flange **304**, and may be configured to fit over the bolt **292** such that the sleeve **302** extends into the first and second openings **288**,**290** while the flange **304** remains above the second surface **296**. The washer **300** may be configured to fit over the bolt **292** between the second surface **296** and the flange **304** of the bushing **298**. In one implementation, the washer **300** may be constructed of a metal or other material which is dissimilar to the metal or other material of the second surface **296** so as to minimize galling and binding when the washer **300** moves against the second surface **296**. In one implementation, the washer **300** may be configured to maintain a space of approximately between three thousandths of an inch and twelve thousandths of an inch, or approximately between five thousandths of an inch and ten thousandths of an inch, between the washer **300** and the flange of the bushing **298** to facilitate the relative movement between the mandrel segment **276** and the substructure **268**.

In operation, the second surface **296** may be coupled with (by, e.g., bolts) or otherwise physically associated with the mandrel segment **276**; the first and second surfaces **294**,**296** may be brought together such that the first and second openings **288**,**290** are aligned; the bolt **292** may be inserted through the first and second openings **288**,**290** and the washer **300** and bushing **298** may be applied over the bolt **292**; and the bolt **292** may be tightened to secure the mandrel segment **276** to the substructure **268** (with, e.g., a nut **306**). Thereafter, the directional type of attachment mechanisms **282**B and the non-directional type of attachment mechanisms **282**C may allow the mandrel segment **276** and the substructure **268** to move relative to each other due to, e.g., differential thermal expansion.

In one implementation, the mandrel segments **76** may be provided with grooves **84** to accommodate the uncured and/or cured material cutting mechanisms **59**,**62** to facilitate cutting the part **42** along defined lines in a plurality of part segments **86**. In one implementation, the part segments **86** may reassembled by being butt-joined together. In other implementations, the mandrel segments **76** may be configured to shape the part segments **86** to facilitate reassembly. For example, the mandrel segments **76** may be configured to impart joggle structures or other joining structures to enable lap-splicing and/or otherwise joining the part segments **86** together to reform the large composite part **42**.

Referring particularly to FIG. **6**, the one or more caul plates **78** may be configured to be positioned over the fabricated part **42** on the mandrel segments **76** and to provide a smoother finish to the cured part **42**. In this example implementation, the caul plates **78** may be secured in position by vacuum bagging. In one implementation, each caul plate **78** may be constructed of bismaleimide composite and may have a thickness of approximately between one-sixteenth inch and one-half inch, or between one-sixteenth inch and one-quarter inch, or one-eighth inch.

Referring particularly to FIGS. **4** and **5**, the first and second rotation support mechanisms **48** may be configured to engage and cooperate with the first and second interface rings **72**,**74** to allow for rotating the tool **44** approximately between one degree and three hundred and sixty degrees, or between one degree and one hundred and eighty degrees, during fabrication, curing, and or removal of the part **42**. In one implementation, the rotation support mechanisms **48** may be further configured to engage and cooperate with the first and second interface rings **72**,**74** to allow for lifting the tool **44** approximately between one inch and thirty-six inches, or between one inch and twenty-eight inches, or between one inch and twenty inches. In various implementations, the first and second rotation support mechanisms **48** may be separate units or may be connected together.

The one or more fixed support mechanisms **50** may be configured to receive and physically support the tool **44** during various processes, including receiving and physically supporting the tool **44** and the fabricated part **42** thereon during the curing process. In one implementation, the fixed support mechanisms **50** may engage and cooperate with the first and second interface rings **72**,**74** to support the tool **44**. In one implementation, the fixed support mechanisms **50** may be further configured to engage and cooperate with the first and second interface rings **72**,**74** to allow for lifting the tool **44** approximately between one inch and thirty-six inches, or between one inch and twenty-eight inches, or between one inch and twenty inches. In various implementations, the first and second fixed support mechanisms **50** may be separate units or may be connected together.

The one or more guided vehicles **52** may be configured to be positioned under or otherwise receive or engage the rotation and/or fixed support mechanisms **48**,**50** and facilitate moving the support mechanisms **48**,**50** and the tool **44** supported thereon to and from, e.g., the automated fiber placement machine **58** and/or curing mechanism **60**. In one implementation, the guided vehicles **52** may be manually guided, while in another implementation, the guided vehicles **52** may be computer guided.

Referring particularly to FIG. **7**, the one or more mandrel segment and caul plate handling mechanisms **54** may be configured to facilitate lifting and positioning the mandrel segments **76** and attaching the mandrel segments **76** to the substructure **68**, to facilitate removing the mandrel segments **76** from the substructure **68**, to facilitate lifting and positioning the caul plates **78** and securing the caul plates **78** (by, e.g., vacuum bagging) over the fabricated part **42** prior to curing, and to facilitate removing the caul plates **78** following curing. Referring particularly to FIG. **8**, the one or more part segment handling mechanisms **56** may be configured to facilitate lifting and removing the part segments **86** from the tool **44** following fabrication, curing, and segmentation of the part **42**. In various implementations, the part segment handling mechanisms **56** may include edge wedges and clamps to facilitate removal and securement of the part segment **86** from the mandrel segment **76**, headers and clamps configured to facilitate removal and securement of the part segment **86** from the mandrel segment **76**, and vacuum cups configured to facilitate securing the part segment **86**. Each of the various handling mechanisms **54**,**56** may be movably positionable or fixedly positioned above, below, or beside the tool **44**, as desired or required by a particular application. Each of the handling mechanisms **54**,**56** may employ vacuum or non-vacuum technologies for engaging the mandrel segment **76**, caul plate **78**, and/or part segment **86**.

The automated fiber placement machine **58** may be configured to apply a composite material comprising resin and synthetic fibers onto the one or more mandrel segments **76** to fabricate the large composite part **42** as a single piece on the tool **44**. The uncured material cutting mechanism **59** may be configured to cut or otherwise segment the fabricated single piece on the tool **44** into a plurality of untrimmed part segments **85** prior to curing. The autoclave or other curing mechanism **60** may be configured to cure the composite material on the one or more mandrel segments **76** to cure the large composite part **42** on the tool **44**. The cured material cutting mechanism **62** may be configured to cut or otherwise segment the fabricated and cured part **42** on the tool **44** into the plurality of trimmed part segments **86** which may then be removed from the tool **44** without disassembling the tool **44**. In various implementations, the cutting mechanism **62** may include drills, punches, knives, saws, and/or discs. The reassembly mechanism **64** may be configured to joining the plurality of trimmed part segments **86** so as to reform the large composite part **42** into a single piece off the tool **44**. In one implementation, the reassembly mechanism **64** may include a fastener gun and the fasteners may include rivets, interference-fit fasteners, and/or bolts.

Referring to FIGS. **9-18**, an example implementation of the above-described method **140** is shown adapted for fabricating the large, generally cylindrical composite fuselage part **42**, wherein the composite fuselage **42** is at least partially fabricated and cured on the tool **44**, cut or otherwise segmented into the plurality of part segments **86** to facilitate removing it from the tool **44** without disassembling the tool **44**, removed from the tool **44**, and then reassembled off the tool **44** to reform the large composite fuselage part **42**. In one implementation, the method **140** may employ some or all of the components of the above-described example system **40**.

The tool **44** may be assembled by attaching the one or more mandrel segments **76** to the substructure **68**, as shown in **142**. In one implementation, the tool **44** may be mounted on the rotatable or fixed support mechanisms **48**,**50**, as shown in **144**, and rotated or fixedly supported as desired or required, as shown in **146** and FIG. **9**.

The part **42** may be at least partially fabricated as a single piece on the tool **44**, as shown in **148**. In one implementation, the fabrication process may include installing and compacting stringer charges to form stringers on the part **42**, installing and inflating bladders to form the stringers or other structural components, and installing and compacting inner mold line plies, while rotating the tool **44** as desired or needed for better access. The guide vehicles **52** may then transport the tool **44** to the automated fiber placement machine **58**, as shown in FIG. **10**. The automated fiber placement machine **58** may receive the tool **44**, such as by engaging the interface rings **72**,**74**, and the rotatable or fixed support mechanisms **48**,**50** and guided vehicles **52** may be removed. The automated fiber placement machine **58** may wrap the entire tool **44** or may wrap each mandrel segment **76** individually and apply connecting straps between individual mandrel segments **76**, as shown in **150** and FIG. **11**. When fabrication is complete, the tool **44** may then be disengaged from the automated fiber placement machine **58**, remounted on the rotatable or fixed support mechanisms **48**,**50** and guided vehicles **50**, and transported to the caul plate handling mechanisms **54**.

The one or more caul plates **78** may be secured (by, e.g., vacuum bagging) over the fabricated part **42**, as shown in **152** and FIG. **12**. In one implementation, the large composite part may be cut or otherwise segmented with the uncured material cutting mechanism **59** into the plurality of untrimmed part segments **85** prior to the curing process, as shown in **153**. In one implementation, the tool **44**, with the caul plates installed **78**, may be transported to the curing mechanism **60** for curing. The fabricated part **42** may be at least partially cured by the curing mechanism **60** on the tool **44**, as shown in **154**. In one implementation, following curing, the tool **44** may be moved to the caul plate handling mechanism **54** and the caul plates **78** may be removed.

The at least partially fabricated and cured part **42** may be cut or otherwise segmented by the cutting mechanism **62** into the plurality of trimmed part segments **86** prior to removal from the tool **44**, as shown in **156**. The trimmed part segments **86** may be removed from the tool **44** by the part segment handling mechanism **56** without disassembling the tool **44**, as shown in **158** and FIG. **13**. In one implementation, the part segments **86** may be further trimmed and/or drilled prior to removal from the tool **44**. The part segments **86** may be reassembled off the tool **44** to reform the single piece large composite fuselage **42**, as shown in **160** and FIG. **17**. In one implementation, this may include further trimming and/or drilling and/or non-destructive inspection of the part segments **86** prior to, during, and or after reassembly, as shown in **162** and FIGS. **14-16**. Non-destructive inspection may be performed for, e.g., inner mold line, outer mold lines, and/or stringers or other structural components.

Although the invention has been described with reference to the one or more embodiments illustrated in the figures, it is understood that equivalents may be employed and substitutions made herein without departing from the scope of the invention as recited in the claims.

Having thus described one or more embodiments of the invention, what is claimed as new and desired to be protected by Letters Patent includes the following:

The invention claimed is:

1. A tool for supporting a large composite part during a fabrication process and a curing process, the tool comprising:

a substructure and a mandrel segment removably attached to the substructure and providing a surface on which the large composite part is fabricated and cured, wherein the substructure is constructed of a first material having a first coefficient of thermal expansion and the mandrel segment is constructed of a second material having a second coefficient of thermal expansion which is different from the first coefficient of thermal expansion;

a first attachment mechanism attaching the mandrel segment to the substructure at a first location and not allowing relative movement between the mandrel segment and the substructure at the first location; and

a second attachment mechanism attaching the mandrel segment to the substructure at a second location and allowing relative movement in at least one direction due to differential thermal expansion between the mandrel segment and the substructure at the second location.

2. The tool of claim 1, wherein the large composite part has a length of at least five meters and is part of an aircraft fuselage.

3. The tool of claim 1, the second attachment mechanism comprising an elongated opening which is oriented along a line in a first direction and which allows the relative movement along the line in the first direction due to the differential thermal expansion between the mandrel segment and the substructure at the second location.

4. The tool of claim 1, the second attachment mechanism comprising an oversized opening which allows the relative movement on a plane in any direction due to the differential thermal expansion between the mandrel segment and the substructure at the second location.

5. The tool of claim 1, the second attachment mechanism comprising an elongated opening which is oriented along a line in a first direction and which allows the relative movement along the line in the first direction, and the tool further comprising a third attachment mechanism attaching the mandrel segment to the substructure at a third location and comprising an oversized opening which allows the relative movement on a plane in any direction due to the differential thermal expansion between the mandrel segment and the substructure at the third location.

6. The tool of claim 1, further comprising:

a center hub extending through a longitudinal axis of the substructure;

a first interface element coupled with a first end of the center hub and a second interface element coupled with a second end of the center hub; and

a rotation mechanism coupled with the first and second interface elements and allowing the tool to be rotated about the longitudinal axis.

7. A tool for supporting a large composite part during a fabrication process and a curing process, the tool comprising:

a substructure and a mandrel segment removably attached to the substructure and providing a surface on which the large composite part is fabricated and cured, wherein the substructure is constructed of a first material having a first coefficient of thermal expansion and the mandrel segment is constructed of a second material having a second coefficient of thermal expansion which is lower than the first coefficient of thermal expansion; and

a plurality of attachment mechanisms attaching the mandrel segment to the substructure, each attachment mechanism comprising a first opening associated with the substructure, a second opening associated with the mandrel segment, and a bolt extending through the first and second openings and removably securing the mandrel segment to the substructure, the plurality of attachment mechanisms comprising:

a first attachment mechanism attaching the mandrel segment to the substructure at a first location, wherein the first and second openings of the first attachment mechanism are a same size and a same shape such that the first attachment mechanism does not allow relative movement between the mandrel segment and the substructure at the first location, and

a second attachment mechanism attaching the mandrel segment to the substructure at a second location and allowing relative movement in at least one direction due to differential thermal expansion between the mandrel segment and the substructure at the second location.

8. The tool of claim 7, wherein at least one of the first and second openings of the second attachment mechanism is elongated along a line in a first direction such that the second attachment mechanism allows the relative movement along the line in the first direction.

9. The tool of claim 7, wherein at least one of the first and second openings of the second attachment mechanism is larger than the other such that the second attachment mechanism allows the relative movement on a plane in any direction.

10. The tool of claim 7, the plurality of attachment mechanisms further comprising a third attachment mechanism attaching the mandrel segment to the substructure at a third location and allowing relative movement along a line in at least one direction due to differential thermal expansion between the mandrel segment and the substructure at the third location.

11. The tool of claim 10, wherein at least the second and third attachment mechanisms are oriented such that the relative movements at the second and third locations are co-planar.

12. The tool of claim 7, each attachment mechanism further comprising:

a first surface physically associated with the substructure, wherein the first opening extends through the first surface;

a second surface physically associated with the mandrel segment, wherein the second opening extends through the second surface; and

a bushing and a washer fitted over the bolt.

13. The tool of claim 12, the bushing comprising a sleeve and a flange, and the bushing is fitted over the bolt such that the sleeve extends into the first and second openings and the flange remains above the second surface.

14. The tool of claim 12, wherein the washer is fitted over the bolt and between the second surface and the flange of the bushing, and the washer maintains a space of between three thousandths of an inch and twelve thousandths of an inch between the washer and the flange of the bushing to facilitate the relative movement of the mandrel segment and the sub structure.

15. The tool of claim 7, further comprising:

a center hub extending through a longitudinal axis of the substructure;

a first interface element coupled with a first end of the center hub and a second interface element coupled with a second end of the center hub; and

a rotation mechanism coupled with the first and second interface elements and allowing the tool to be rotated about the longitudinal axis.

16. A tool for supporting a large composite part during a fabrication process and a curing process, the tool comprising:

a substructure and a mandrel segment removably attached to the substructure and providing a surface on which the large composite part is fabricated and cured, wherein the substructure is constructed of a first material having a first coefficient of thermal expansion and the mandrel segment is constructed of a second material having a second coefficient of thermal expansion which is lower than the first coefficient of thermal expansion; and

a plurality of attachment mechanisms attaching the mandrel segment to the substructure, with each attachment mechanism comprising a first opening associated with the substructure, a second opening associated with the mandrel segment, and a bolt extending through the first and second openings and removably securing the mandrel segment to the substructure, the plurality of attachment mechanisms comprising:

a first attachment mechanism attaching the mandrel segment to the substructure at a first location, wherein the first and second openings of the first attachment mechanism are a same size and a same shape such that the first attachment mechanism does not allow relative movement between the mandrel segment and the substructure at the first location,

a second attachment mechanism attaching the mandrel segment to the substructure at a second location and allowing relative movement along a line in a particular direction due to differential thermal expansion between the mandrel segment and the substructure at the second location, and

a third attachment mechanism attaching the mandrel segment to the substructure at a third location and allowing relative movement on a plane in any direction due to differential thermal expansion between the mandrel segment and the substructure at the third location,

wherein at least the second and third attachment mechanisms are oriented such that the relative movements at the second and third locations are co-planar.

17. The tool of claim **16**, wherein at least one of the first and second openings of the second attachment mechanism is elongated along the line in the particular direction such that the second attachment mechanism allows the relative movement along the line in the particular direction.

18. The tool of claim **16**, wherein at least one of the first and second openings of the third attachment mechanism is larger than the other such that the third attachment mechanism allows the relative movement on the plane in any direction.

19. The tool of claim **16**, each attachment mechanism further comprising:

a first surface physically associated with the substructure, wherein the first opening extends through the first surface;

a second surface physically associated with the mandrel segment, wherein the second opening extends through the second surface;

a bushing fitted over the bolt, the bushing comprising a sleeve and a flange and fitted over the bolt such that the sleeve extends into the first and second openings and the flange remains above the second surface; and

a washer fitted over the bolt and between the second surface and the flange of the bushing, the washer maintaining a space of between three thousandths of an inch and twelve thousandths of an inch between the washer and the flange of the bushing to facilitate the relative movement of the mandrel segment and the substructure.

20. The tool of claim **16**, further comprising:

a center hub extending through a longitudinal axis of the substructure;

a first interface element coupled with a first end of the center hub and a second interface element coupled with a second end of the center hub; and

a rotation mechanism coupled with the first and second interface elements and allowing the tool to be rotated about the longitudinal axis.

* * * * *